HYDROGEOLOGIC CHARACTERIZATION OF A GLACIAL AQUIFER

CONTAMINATED BY CRUDE OIL NEAR BEMIDJI, MINNESOTA

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To Lale, Sule, Neslihan, and Betin, for their strength and courage,

especially Sule, for explaining

HYDROGEOLOGIC CHARACTERIZATION OF A GLACIAL AQUIFER CONTAMINATED BY CRUDE OIL NEAR BEMIDJI, MINNESOTA

by SEVIN ILHAN BILIR, B. S.

THESIS

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Although they may never read this, the folks on the R/V Maurice Ewing deserve the credit for recharging my mental systems, especially Rob and Steffen for sharing their neverending joy of hacking. I thank Stacey, Keg, Carmen, Paula, Obiwan, and especially, Andy for the good times and for being there in hard times when I needed their friendship most. Most of all I am grateful to my family for their interest in my studies, their ability to deal with my impatience, and for their unconditional love.

This thesis was submitted to the Committee on June 2, 1992.

ABSTRACT

HYDROGEOLOGIC CHARACTERIZATION OF A GLACIAL AQUIFER CONTAMINATED BY CRUDE OIL NEAR BEMIDJI, MINNESOTA

by

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SUPERVISING PROFESSOR: PHILIP C. BENNETT

This study investigates the hydrogeology of a glacial sand and gravel aquifer contaminated by crude oil near Bemidji, Minnesota. The goal of this study is to obtain an understanding of the effect of local flow phenomena, glacial stratigraphy, and climatic and surficial factors, on the groundwater flow behavior. The study determines the geohydrologic parameters of the study area that was affected by the oil spill, and identifies the dominant controls on fluid flow and the impact of seasonal variations.

The study area lies on a flat to gently rolling outwash plain having a regional hydraulic gradient of 0.0028 towards N70°E. Locally, the shallow unconfined aquifer has a lower boundary consisting of a low permeability basal till unit located at approximately 23-31 m depth and is overlain by approximately 10 m of stratified morainal drift, containing discontinuous lenses of till, sediment-flow deposits, and lacustrine silt and clay. An unconformity separates the drift from approximately 7 m of outwash sands and gravels consisting of layers of fine grained sand and silt. The site is situated on a small recharge zone of a local flow system, which discharges into a small lake 350 m downgradient from the initial oil pool.

Vegetation and geomorphological surveys, infiltration rate measurements, and soil organic carbon analyses were used to investigate the complexities of focused recharge. Surface water flow is directed to points of focused recharge. In the *spray zone*, where water flows over oily sediment, contaminated waters enter the unsaturated zone and possibly reach the water table. Monitoring wells were emplaced to gather stratigraphy and seasonal water level data, which indicated local flow variations particularly during times of extreme recharge and in areas with a shallow water table. Water levels are usually high from June to the early part of autumn and then

drop off steadily throughout the year. In the wetland a water level decrease of 0.5 m occurred over one month during a dry summer. However, an average decrease of less than 10 cm was observed in the rest of the site. Mounding of the water table typically occurs in the summer and at points of focused recharge, probably in response to the uneven distribution of recharge and hydraulic conductivity. The wetland is a flow-thru lake or a discharge mound for most of the year, yet following large events of precipitation it is a recharge mound. Hydraulic conductivity and sediment anisotropy were quantified by measuring grain-size distribution and bulk and individual hydraulic conductivities of intact core sediments. Sediment is mostly medium sands with lenses of silt and gravel. Adjacent layers may differ in hydraulic conductivity by more than three orders of magnitude. Measured hydraulic conductivities ranged from 1×10^{-8} to 1×10^{-4} m/s with an average of 2.02×10^{-5} m/s, indicating mostly sand size sediments. Hydraulic conductivities of homogeneous sediments did not vary outside an order of magnitude, however, hydraulic conductivities of heterogeneous sediments were found to range over 4 orders of magnitude. Anisotropy ratios averaged 1.4 and 15 for calculated and measured hydraulic conductivities, respectively, indicating a complex flow field dominated by horizontal flow. Thin fine-grained layers affect the vertical flow rates to a large degree.

MODFLOW, a three-dimensional finite-difference groundwater flow model, was used to simulate the effects of a changing hydrologic budget on the local flow system, incorporating the detailed information on hydraulic parameters and recharge rates determined during this study. Steady-state modeling confirmed that the complexities at the site could not be modeled under simple homogeneous conditions, but required a variable distribution of hydraulic conductivities. The influences of climatic factors were seen in consecutive steady-state models to support observations that evapotranspiration and recharge play an important role, particularly where the water table is shallow.

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I. INTRODUCTION

Throughout the populated northeast, glacial deposits are important sources for water supply and waste disposal locations. Understanding the extreme variations in the geologic environments is an important step to quantifying the hydrogeologic systems. In the past, unconfined glacial aquifers have been considered to be regionally homogeneous with respect to geology and hydrology. However, it is apparent that glacial sediments are, in fact, not homogeneous but highly variable in both the hydrologic and geologic systems. On a smaller scale, sediments can be extremely heterogeneous and more often than not, create local perturbations in the hydrologic and geologic systems. Small scale differences in the hydrologic budget also modify the flow field, causing fluctuations in the local groundwater system. This study investigates the hydrogeologic conditions and interrelationships of an unconfined sand and gravel aquifer contaminated by crude oil.

On August 20, 1979, a high pressure oil pipeline burst, 2.5 m below the ground surface spilling crude oil onto the ground surface. The pipeline had a diameter of 86.4 cm and was under a pressure of 3.48×10^6 N/m^2 (500 psi). Approximately 1.5×10^6 *l* of crude oil was ejected onto the land (Hult, 1984). An area, termed the *spray zone* throughout this thesis, was covered with oil that sprayed out of the high pressure pipeline.

At the point of rupture, a large pool of oil collected on the ground surface in a slight topographic depression. Oil filled up and spilled out of the depression and drained overland to a small wetland, where a second pool of oil formed on the water surface . In both locations, oil infiltrated down to the water table. Approximately 4×10^5 *l* of crude oil escaped to the aquifer before the oil spill was discovered (Hult, 1989). Approximately 8550 m^2 (2.1 acres) of the soil surface was contaminated by the drained and sprayed oil (Hult, 1984) (Figure I.1).

Lakehead Pipeline Company, the responsible party, began cleanup of the site within one week. Land treatment, collection of crude oil by means of trenching and pumping from the ground and water surfaces, and burning and evaporation of crude oil were the only methods of remediation used at the site. Approximately 1.1×10^5 *l* of crude oil were collected from the ground and water

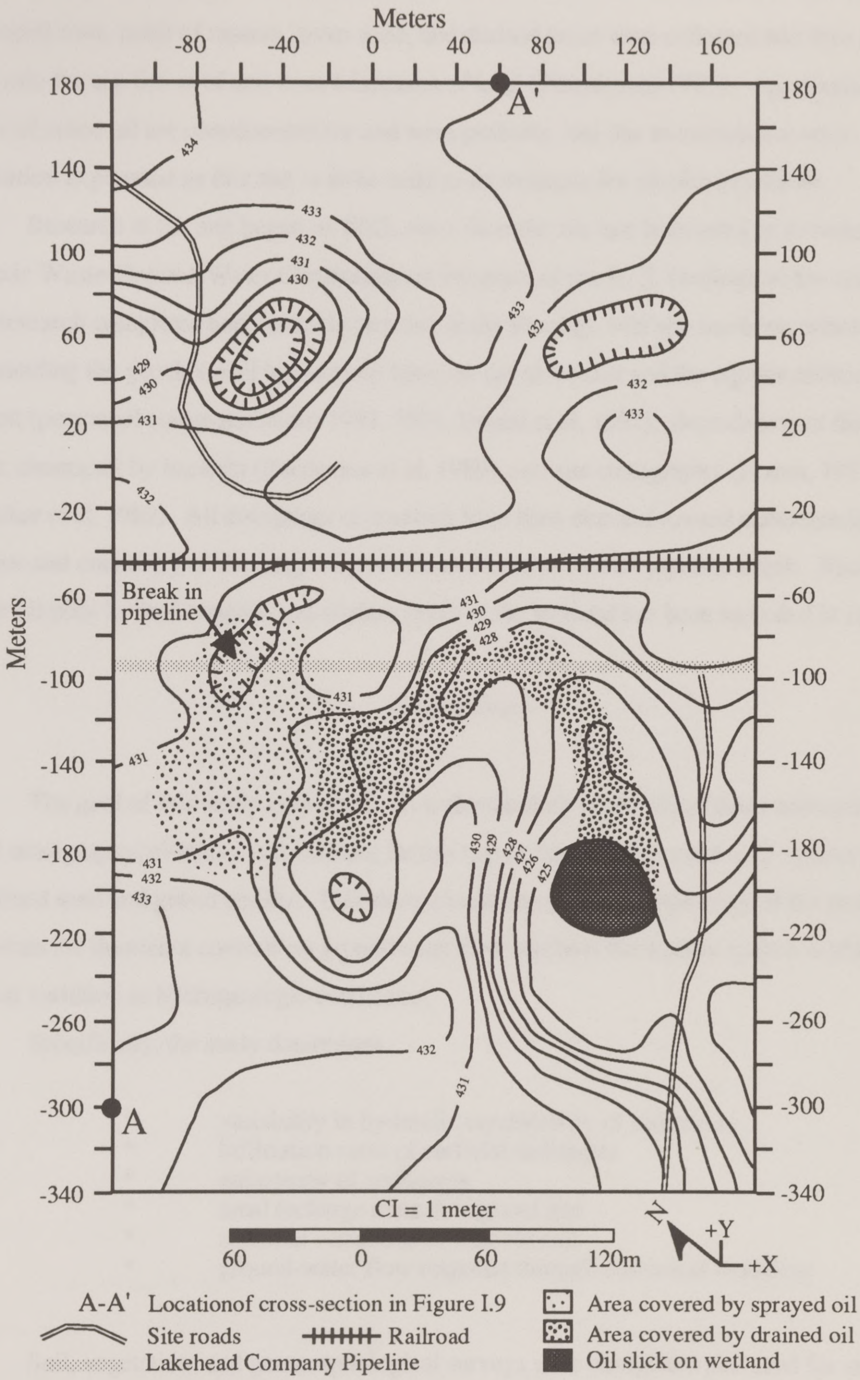


Figure I.1 Topographic map of study area with location of areas affected by overland spray and draining of crude oil.

surfaces and then transported off the site (Hult, 1987). 765 m^3 of contaminated soils, from the unsaturated zone, point of rupture, *spray zone*, and drained areas were collected and then plowed and mixed into the top 0.6 m of soil over 6 hectares of land (Pfannkuch, 1979). Approximately $4x10^4$ *l* of crude oil are unaccounted for and were probably lost due to calculation error. No further remediation is planned as this site is to be used as an example for similar situations.

Research at the site began in 1983, since then the site has been used as a research site by the Toxic Waste-Ground-Water Contamination Program of the U. S. Geological Survey. The bulk of the research completed and currently ongoing at the Bemidji, MN site has been oriented towards understanding the geochemical interactions between the oil bodies and the aquifer sediments (Bennett (personnel communication) 1991, 1991; Essaid et al, 1991), degradation of dissolved organic chemicals by bacteria (Baedecker et al, 1989), and site stratigraphy (Franzi, 1987, 1988; Baedecker et al, 1989). All disciplines of research have been directed toward understanding the behavior and chemistry of the large oil pool located near the initial pipeline break. Recently, the smaller oil pool located beneath and slightly north of the wetland has been included in research.

Objectives

The goal of this study is to obtain an understanding of the effect that hummocky terrain, glacial stratigraphy, climatic, and surficial factors has on the local groundwater system in an unconfined sand and gravel aquifer. This study characterizes the hydrogeology of the area and determines the dominant controls on groundwater flow and how the aquifer system is affected by seasonal variation in hydrogeologic conditions.

Specifically, the study determines

* variability in hydraulic conductivity of sediments
* infiltration rates of surficial sediments
* anisotropy of sediments
* areal recharge rates throughout site
* seasonal variations in water levels
* ground-water flow response through numerical modeling

Soil, vegetation, and geomorphological surveys were completed and used for selection of infiltration rate measurement locations. Surficial soil samples and core sediments from newly installed wells were collected for determination of stratigraphy and characteristics of surficial sediments. Hydrogeological maps were generated using measured and historical water level elevations, and were used to determine local flow phenomena and seasonal responses. Characterizing the type of surficial sediments and the physical lay of the land helped determine the interrelationships affecting local flow phenomena.

Specific laboratory tasks consisted of measurement of total organic carbon of soil samples, description of core sediments, measurement of bulk and individual hydraulic conductivity of intact core sediments, comparisons of calculated and measured hydraulic conductivities, correlation of data to previously determined stratigraphy and hydrogeological parameters, determination of grain-size distribution of core sediments, and the simulation of a hydrologic budget using MODFLOW, a three-dimensional finite-difference ground-water flow model.

Physical Setting

Location & Climate

The Bemidji area is located within the headwaters of the Mississippi river. Surface water drainage, where present, is to the north towards Grant Creek (Oakes and Bidwell, 1968). The research site is located approximately 29 km northwest of Bemidji, Minnesota, in a sparsely populated section of Beltrami County (Figure I.2). The site encompasses approximately 28 hectares and is located on the properties of the State of Minnesota and Lakehead Pipeline Company. Current studies are being conducted by the Minnesota District-Water Resources Division of the U. S. Geological Survey.

High temperatures and precipitation rates occur in the summer months when evapotranspiration is at a maximum. During the winter, mean temperature is extremely low and precipitation is primarily in the form of snow. Snowmelt occurs during the spring months, recharging the groundwater. These extreme conditions may be a primary influence on the local groundwater system.

Mean annual temperature at Bemidji (1941-70) is 3°C (37.4°F) with average monthly extremes of -23°C (-9°F) in January and 27°C (81°F) in July (1951-70) (NOAA, 1982; Kuehnast, 1972). Figure I.3(c) displays average temperature records for 1987-90 at the Bemidji, MN airport. Average temperature for north central Minnesota is shown in Figure I.4(b). Recent (1986-90) temperatures have been higher than normal, however records from the Bemidji airport indicate that

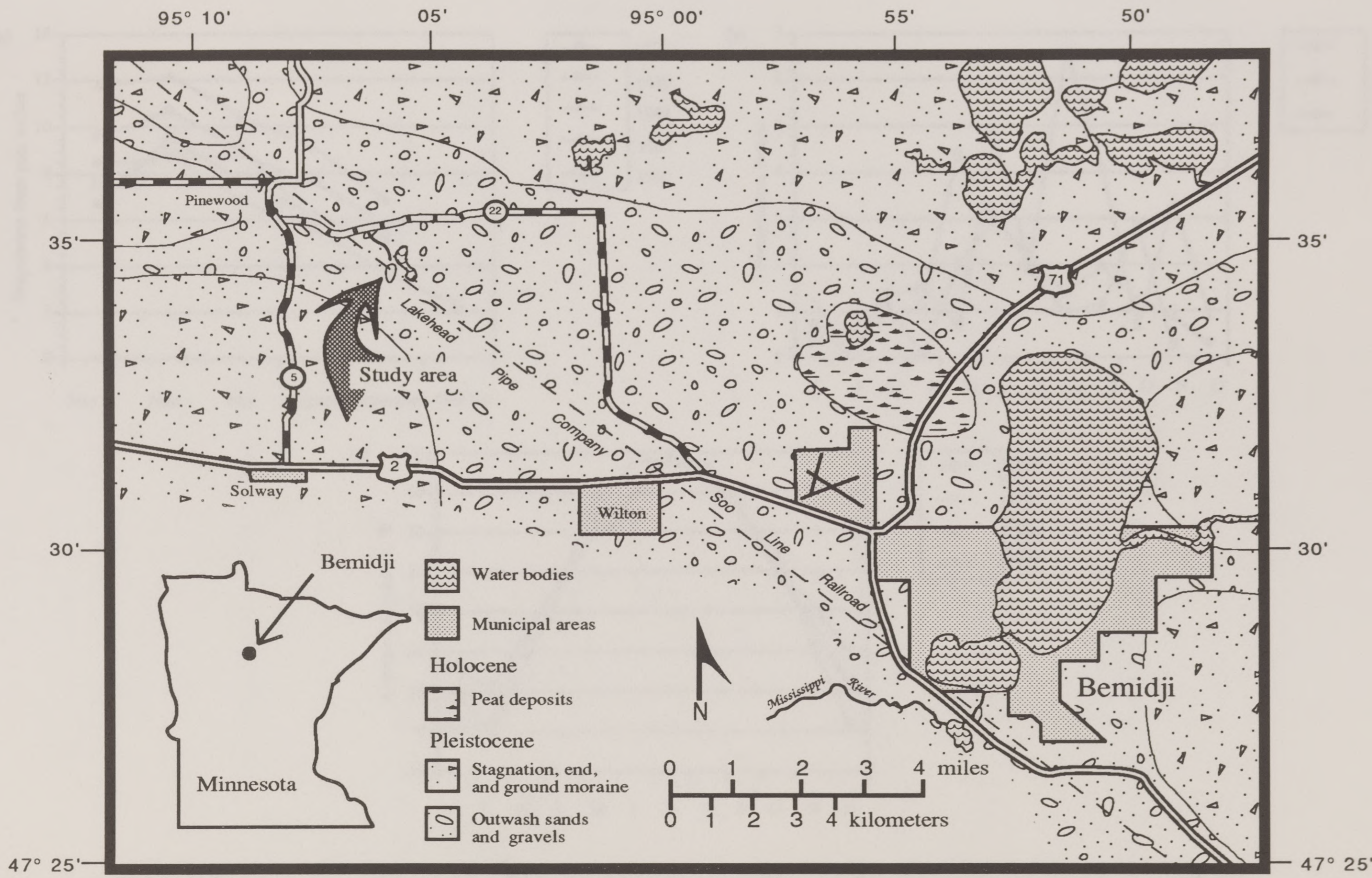


Figure I.2 Quaternary geology of the U. S. Geological Survey-Water Resources Division research site, Bemidji, Minnesota. Modified from Hobbs and Goebel, 1982

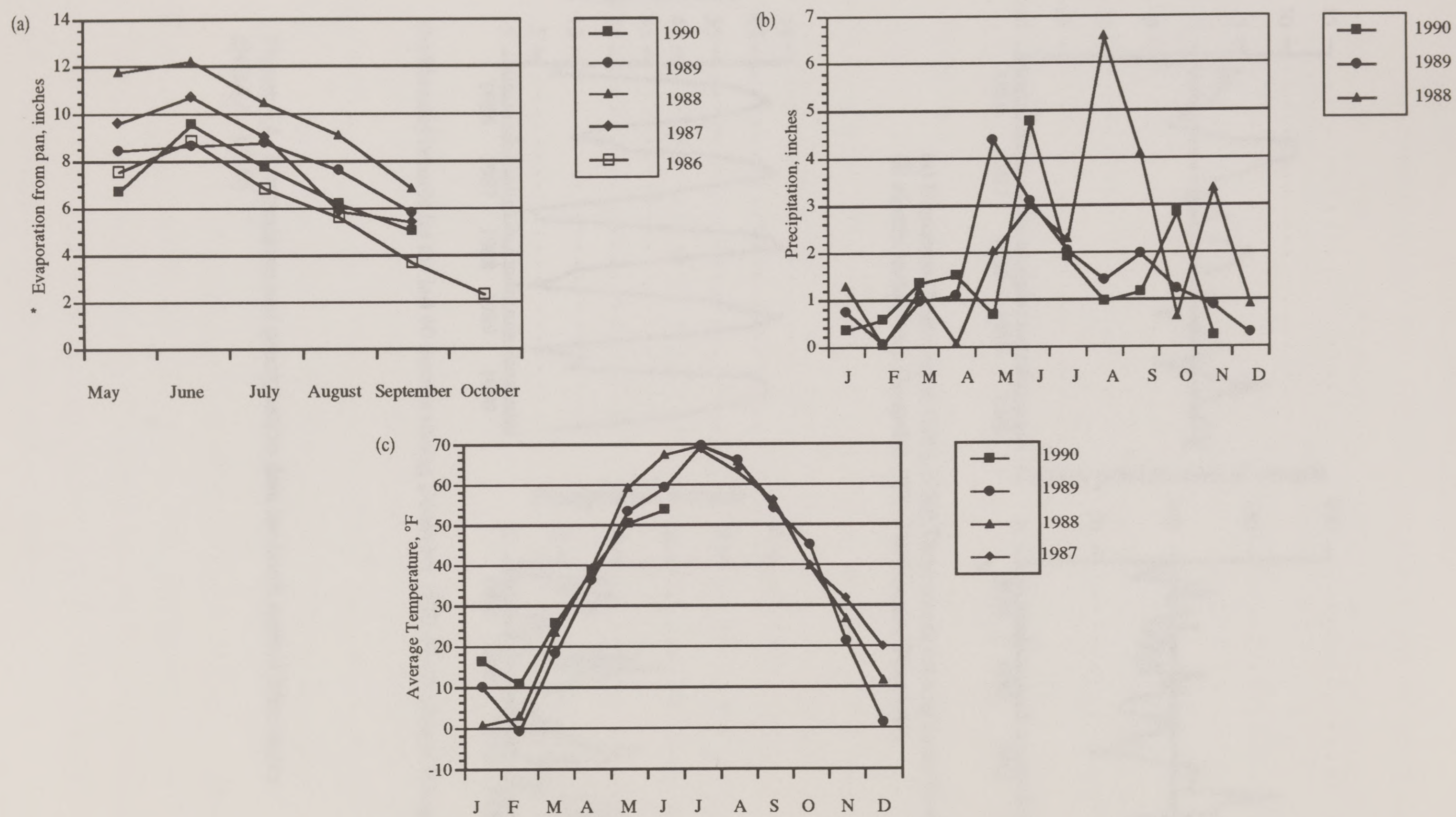
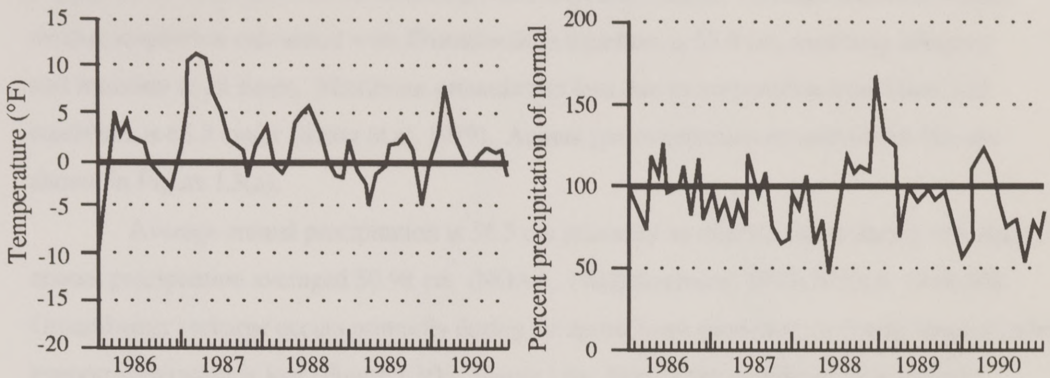
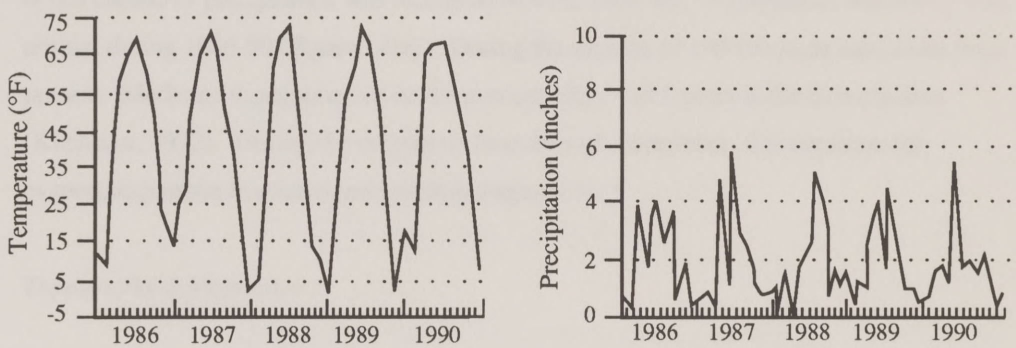


Figure I.3 Climate records taken at Bemidji Airport, approximately 9 miles southeast of the research site (Lat 47°28', Long 94°53', 408.4 m (1340 ft) MSL. * Evaporation measurements taken at Waseca Station (Lat 44°4', Long 93°31'). (NOAA, 1986-90).



(a) Departures from normal (1951-1980) Three month running mean for the 60 months ending with December 1990, North central Minnesota



(b) Monthly records for the last 60 months ending December 1990, North central Minnesota

Figure I.4 Temperature and precipitation data for north central Minnesota (NOAA, 1990) local temperature levels have been average (Figure I.4(a)).

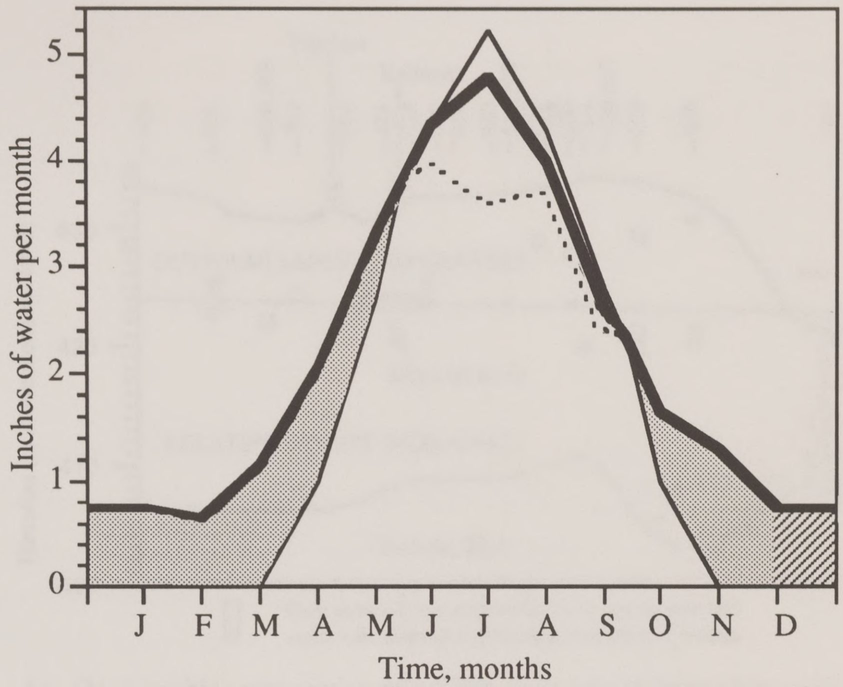
Potential evapotranspiration, calculated from NOAA (1987-90) temperature data, averages 0.38 cm/d and 12 cm/mo during June, July, and August. Average annual potential evapotranspiration calculated with Thornthwaite's equation, is 55.4 cm, assuming adequate soil moisture at all times. Maximum groundwater loss due to evaporation from lakes and reservoirs is 63.5 cm/yr (Baker et al, 1979). Annual pan evaporation records (1986-90) are shown in Figure I.3(a).

Average annual precipitation is 56.5 cm primarily as rainfall, while during this study, annual precipitation averaged 50.98 cm (NOAA, 1982; Kuehnast, 1972; NOAA, 1988-90). Groundwater recharge occurs primarily during the spring from snowmelt, or during showers when evapotranspiration is low (Figure I.3(b); Figure I.5). During the months of May through September when evapotranspiration is highest, an average of 34 cm/mo of the normal annual precipitation occurs (NOAA, 1988-90). In the autumn a short period of high precipitation occurs due to large storms. From November through March, when the ground is frozen, an average total of 6.5 cm/mo of precipitation was recorded (NOAA, 1988-90). Precipitation was lower than normal during 1986-90 (Figure I.4(a)). During the summer of 1990 drought conditions were present. Moderate droughts occur on the average every 4 to 5 years in the Bemidji area (Kuehnast, 1972). During the months of June through September, it is common for evapotranspiration to exceed precipitation (Figure I.5).

Topography & Vegetation

The topography of the site is flat to gently undulating with small depressions and lakes The hummocky terrain slopes gently towards the northeast. Topographic relief is 11.5 m, ranging from 422.5 to 434 m, mean sea level (msl) (Figure I.1). The micromorphology of the terrain includes a kettle, wetland, and a small lake (termed *lake "1386"* throughout this thesis; Figure I.6). *Lake "1386"* covers approximately 20.2 hectares and is less than 2 m deep.

The site is heavily forested, containing several types of natural vegetation. Aspens, birches, pines grow in stands throughout the site, while assorted bushes, grasses, and mosses make up the rest of the site vegetation. Leaves, needles, moss, dead grass and tree limbs cover the ground in the heavily forested areas, whereas moss is more common in lightly forested areas. Grassy localities are covered with sparse moss and dead grass.



EXPLANATION

Precipitation

Potential evapotranspiration (PET)

Actual evapotranspiration (AET)

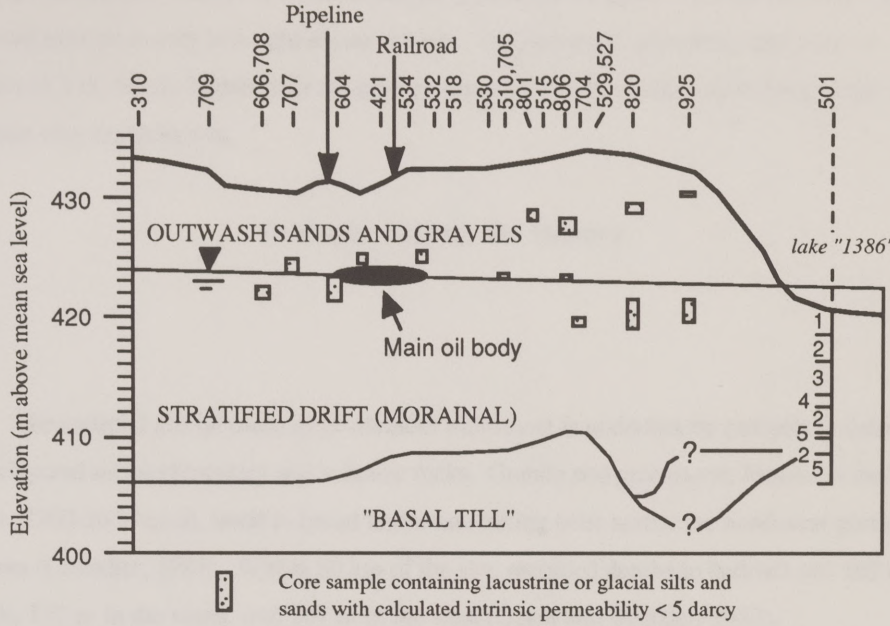
Moisture surplus

Precipitation during this time is in excess of soil needs. Some will infiltrate to ground-water storage; some will run off directly to streams. If moisture occurs as snow, the infiltration or runoff will not occur until the spring thaw.

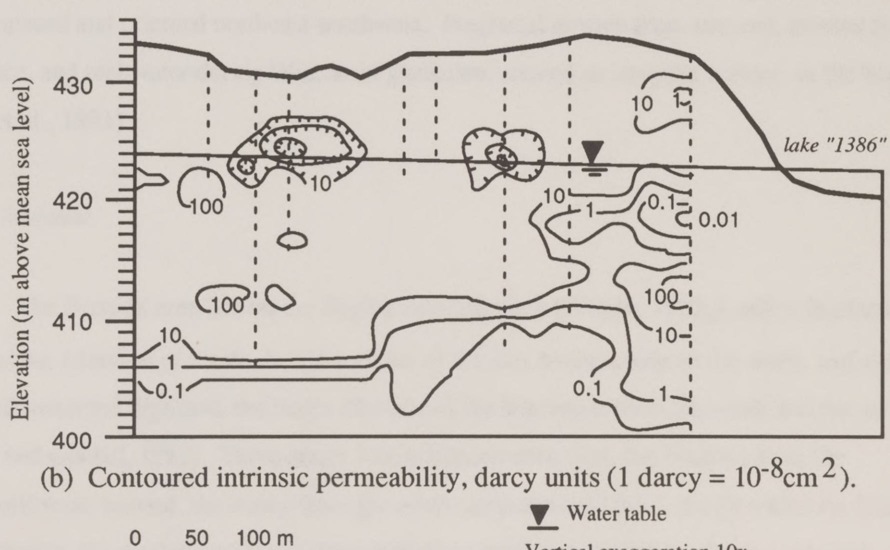
Soil moisture recharge

Precipitation during this time is replenishing soil moisture or, in the case of unmelted snow, is available for soil recharge after thawing occurs.

Figure I.5 Precipitation and evapotranspiration for the Mississippi headwaters watershed, north-central Minnesota (Modified from Oakes and Bidwell, 1968)



(a) Stratigraphic cross section of aquifer along axis of large plume where: 1 = lake bottom sediments, 2 = coarse sand to very coarse gravel, 3 = very fine to fine sand, 4 = fine to coarse sand, 5 = till (taken from drillers log) Core samples were collected during construction of wells listed along cross section.



(b) Contoured intrinsic permeability, darcy units (1 darcy = $10^{-8}cm^2$).

Figure I.6 Geologic and hydrogeologic cross sections at site, determined from grain size analysis. Adapted from Franzi (1988) and Coontz (1991).

During cleanup of the oil spill, several acres of trees were bulldozed and destroyed. Following cleanup activities, several hundred pine saplings were planted across the site. These 12 year-old pine trees vary in height across the site. In some areas, pine trees may reach a maximum of 1 m, barely higher than the grasses, however, in the southwestern area of the site these pines may reach to 4 m.

Geologic Setting & History

Bedrock

The surficial glacial material of northern Minnesota is underlain by complexly deformed and interlayered metasedimentary and volcanic rocks. Granite and greenstone, formed in the Late Archean (2700-2650 mya), trend in broad northeast striking belts across the northwest portion of Minnesota (Chandler, 1981). Within 80 km of the site, recorded depths to bedrock are 165 m in the north, 137 m in the south, and 107 m in the west (Olsen and Mossler, 1982).

The crystalline rock is dense, with low porosity and permeability, and is not considered to be water-bearing except in fractures and near the top in weathered zones. Interpretations of magnetic anomaly maps of the area indicate the presence of large, regional scale, parallel fractures, evenly spaced and oriented northeast-southwest. Preglacial erosion from streams, erosion from glacial ice, and meltwater during Wisconsin glaciation, created an irregular surface on the bedrock (Stark et al., 1991).

Glacial Material

The Bemidji area lies on the Bagley outwash plain (Wright, 1972_b), and is bordered by the Bigstone Moraine of the St. Louis sublobe of the Des Moines lobe to the north, and the low relief, till-veneered highland, the Itasca Moraine of the Wadena lobe to the south and the west (Hobbs and Goebel, 1982). Three major lobe advancements, first, the Wadena from the north-northwest, second, the Rainy from the north-northeast, and third, the Des Moines from the northwest, of late Wisconsin age deposited the sediments found in the Bagley outwash plain (Figure I.7).

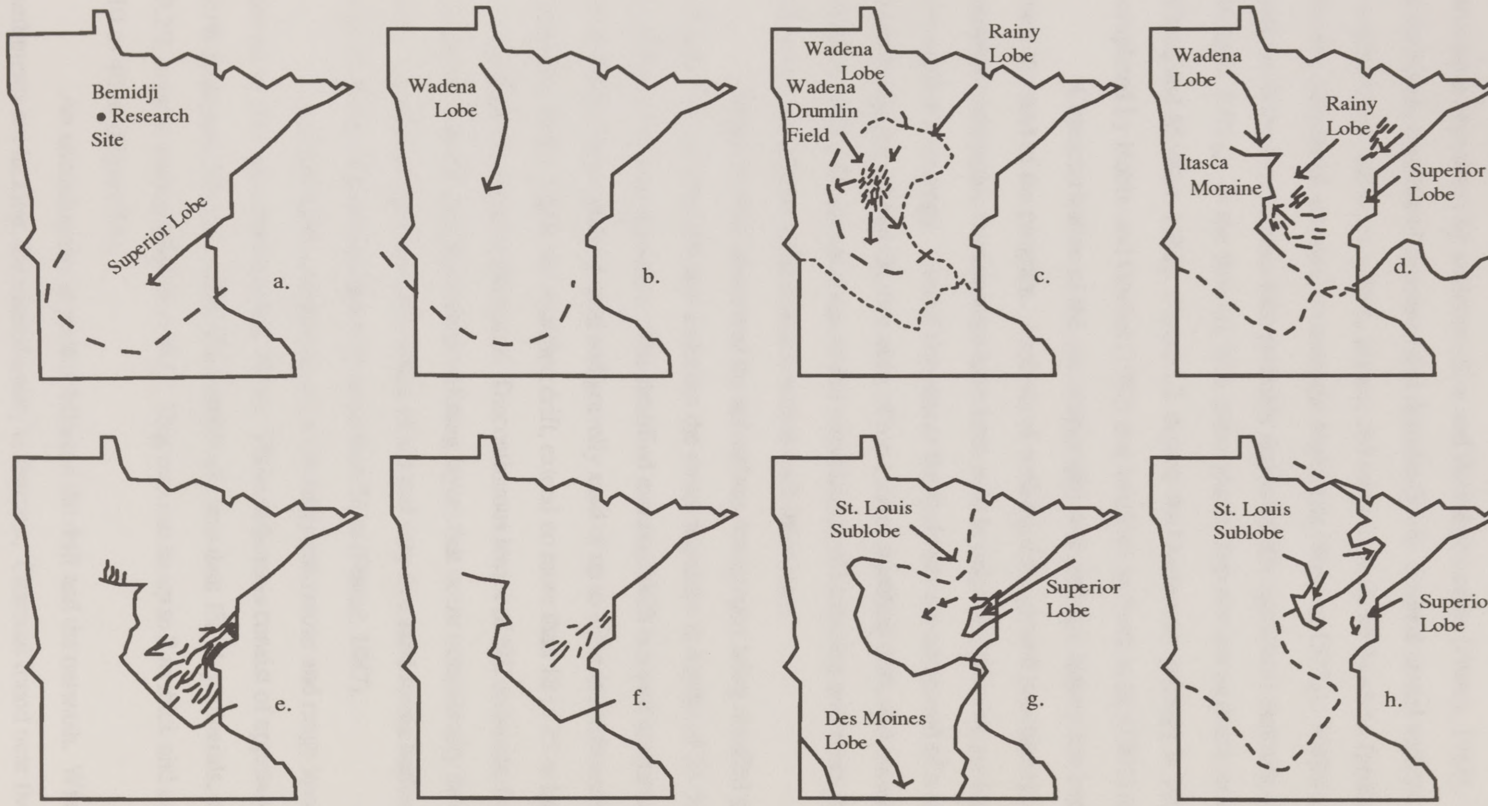


Figure I.7 Phases of glaciation effecting northwestern Minnesota a) Deposition of till deposits by Superior Lobe; b)deposition of till deposits by Wadena lobe; c) Wadena lobe formation of drumlins and advance to moraine in the south (Date early Wisconsin?); d) Advance of Superior and Rainy lobes southwestward and advancement of Wadena lobe to Itasca moraine; formation of drumlins south of Rainy lobe advancement (Date 20 000 BP?); e) Erosion of tunnel valleys beneath Wadena and Superior lobes; f) Deposition of eskers in tunnel valleys; g) Extension of Des Moines lobe southeastward and extension of Superior lobe southwestward (Date 14 000BP?); and h) Advance of Superior lobe to the southwest and St. Louis sublobe to the southeast (Date 12 000BP?). Adapted from Wright (1972_b)

Morainal deposits in the north consist of complexly-interbedded diamicts and gravels indicating deposition by sediment-flow and fluvial processes (Franzi, 1988). The Itasca highland, in the south, consists of moraines and drumlin fields. Several tunnel valleys, large sand-filled troughs, lakes, and bogs, eskers, kames, and other ice-contact deposits, (probably due to southward flowing subglacial streams) transect the highlands (Wright, 1972_a). Meltwater from the St. Louis sublobe of the Des Moines lobe probably deposited the uppermost deposits of sand deposits (Wright, 1972_b). In the Bemidji area, these glacial deposits are as much as 165 m thick (Olsen and Mossler, 1982). Figure I.2 depicts the Quaternary geology in the Bemidji area as completed by Hobbs and Goebel (1982) and modified by Stark et al. (1991) and me.

Characterization of the site stratigraphy and geologic history has been under investigation since the start of the program. Analysis of well-log data, ground penetrating radar, and surface morphostratigraphic relationships have been used in order to determine geological heterogeneities and aquifer anisotropy. Glacial deposits at the study site are composed of a complex assemblage of four lithofacies; a basal till, two units of ice-contact stratified drift, and outwash sands and gravels (Franzi, 1987). Erosional contacts and intercalation of lacustrine sediments indicate separate phases of late glacial sedimentation within each lithofacies.

Franzi (1987) interpreted the subsurface stratigraphy using detailed grain-size analysis (Figure I.6). A basal till unit underlies the entire sequence at depths of 23-31 m and is known to be at least 1-6 m in thickness. The stratified morainal drift is a unit consisting of poorly sorted medium-to coarse-grained sand and gravelly sand of up to 10 m in thickness (Figure I.6). Individual beds, within the stratified drift, extend no more than 10 to 25 m laterally and a few centimeters to meters in thickness. Discontinuous lenses of till, sediment-flow deposits, and lacustrine silt and clay form semiconfining layers that occur occasionally throughout the stratified drift. Lacustrine sediments consisting of silt and very fine sand forms bodies of 1 m thick patches and are believed to extend laterally more than 50 m (Franzi, 1987).

Outwash sands and gravels are moderately calcareous and range in color from yellowish brown to very pale brown (Hult, 1984). These sediments consist of approximately 57% quartz, 29% feldspars, 5% carbonates, 2% hornblende, less than 1% clay minerals, and less than 0.2% organic carbon (Berndt, 1982). This unit can be up to 7 m thick and extend laterally from 10 to 40 m (Figure I.6).

An unconformity is present between the drift and the outwash. Where lacustrine sediments are lacking, the unconformity is sharpest. Charcoal found near the unconformity indicates that an interglacial interlude lasted long enough for kettle lakes to develop thick vegetation (Franzi, 1988). Franzi (1987) found evidence for high angle faulting and disruptive bedding, which indicated kettle development occurring before, during, and after deposition of outwash.

Hydrogeology

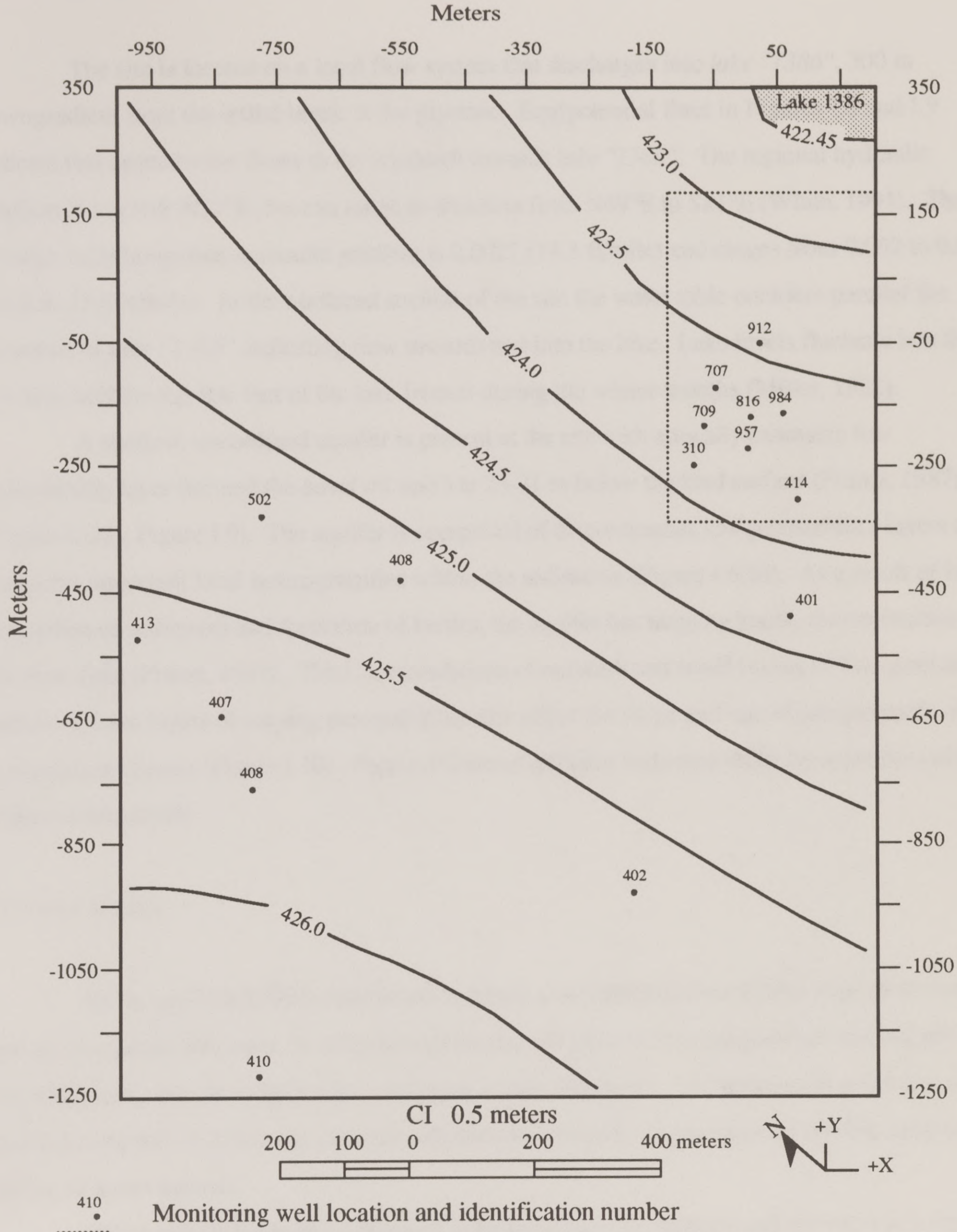
Regional Hydrogeology

In the Bemidji area, the entire thickness of glacial deposits is comprised of confining units of till and lake deposits separating unconfined and confined aquifers. The base of the unconfined aquifer slopes to the east at a gradient of 0.0019 (10 ft/mile). Saturated thicknesses range from 0 to 38 m. Generally, the regional hydraulic gradient is 0.001 (5.3 ft/mile) (Stark et al., 1991) and flows to the northeast. Locally, the groundwater flow direction is approximately N70°E with an average horizontal hydraulic gradient of 0.0028 (15 ft/mile) (Figure I.8) . Direction of flow ranges from N63°E to N78°E. Horizontal hydraulic gradients range from 0.0008 to 0.004 (4 to 21 ft/mile).

Specific capacities of wells in the Bemidji area range from 3 to 81 gpm per foot of drawdown (Oakes and Bidwell, 1968). Horizontal hydraulic conductivities of these aquifer sediments east of Bemidji, MN have been measured at 3.53×10^{-6} to 7.06×10^{-4} m/s (Stark et al., 1991).

Confining units of fine-grained till or lake-deposits are present in the Bemidji area, however, they do not influence local flow in the study area. Thicknesses of the unit can vary from 0.3 to 61 m (Stark et al., 1991). Flow between the uppermost-confined units and the unconfined aquifer is controlled by this low permeability unit. Miller (1982) gives a mean vertical hydraulic conductivity of 6.35×10^{-8} m/s for similar units in the area.

Thicknesses of the uppermost confined-drift aquifer vary from 0 to 18.3 m (Stark et al., 1991). The confined aquifer has a groundwater flow pattern that is similar to that seen in the unconfined unit, however, horizontal hydraulic gradients are usually smaller.



410 • Monitoring well location and identification number

Area outlined in dashes is the location of site water table maps

424.5 — Lines of equal hydraulic head

Lake 1386 (1386 is the average lake elevation above mean sea level (ft))

Figure I.8 Regional water table map, June 1990

Site Hydrogeology

The site is located on a local flow system that discharges into *lake "1386"*, 300 m downgradient from the initial break in the pipeline. Equipotential lines in Figures I.8 and I.9 indicate that groundwater flows to the northeast towards *lake "1386"*. The regional hydraulic gradient is towards N57°E, but can range in direction from N49°E to S81°E (White, 1991). The average local horizontal hydraulic gradient is 0.0027 (14.3 ft/mile) and ranges from 0.002 to 0.003 (10.6 to 15.8 ft/mile). In the northeast section of the site the water table contours parallel the shoreline of *lake "1386"* indicating flow towards and into the lake. Lake levels fluctuate less than 0.3 m/yr and the top few feet of the lake freezes during the winter months (Miller, 1988).

A shallow, unconfined aquifer is present at the site with a locally extensive low permeability layer (termed the *basal till* unit) at 23-31 m below the land surface (Franzi, 1987) (Figure I.6(a); Figure I.9). The aquifer is comprised of discontinuous low permeability layers that represent important local heterogeneities within the sediments (Figure I.6(b)). As a result of both deposition of sediments and formation of kettles, the aquifer has large hydraulic discontinuities in the flow field (Franzi, 1987). Thick accumulations of outwash and small bodies of fine-grained sediment, form layers of varying permeabilities that affect the shape and rate of advancement of the contaminant plumes (Figure I.10). Permeabilities of adjacent beds may differ by more than three orders of magnitude.

Previous Studies

Baehr and Hult (1989) determined air-phase permeabilities over a 20 m zone of the lower part of the unsaturated zone. Results revealed a thin silt layer of fine sand and silt directly above the water table, this same layer has been found in core sediments. The water table never extends upward more than 2 m into the outwash, whether this is due to the presence of the fine sand and silt layer is not known.

White (1991) found that horizontal flow varied in both velocity and direction to a much wider degree than was earlier estimated by others. Measured velocities ranged from 0.034 to 2.2 m/d and in directions of N49°E to S81°E. Downgradient of the railroad, the average hydraulic conductivity is 1.5×10^{-3} m/s, while upgradient hydraulic conductivities averaged 3.1×10^{-4} m/s, indicating that sediments were more permeable in the area upgradient of the railroad.

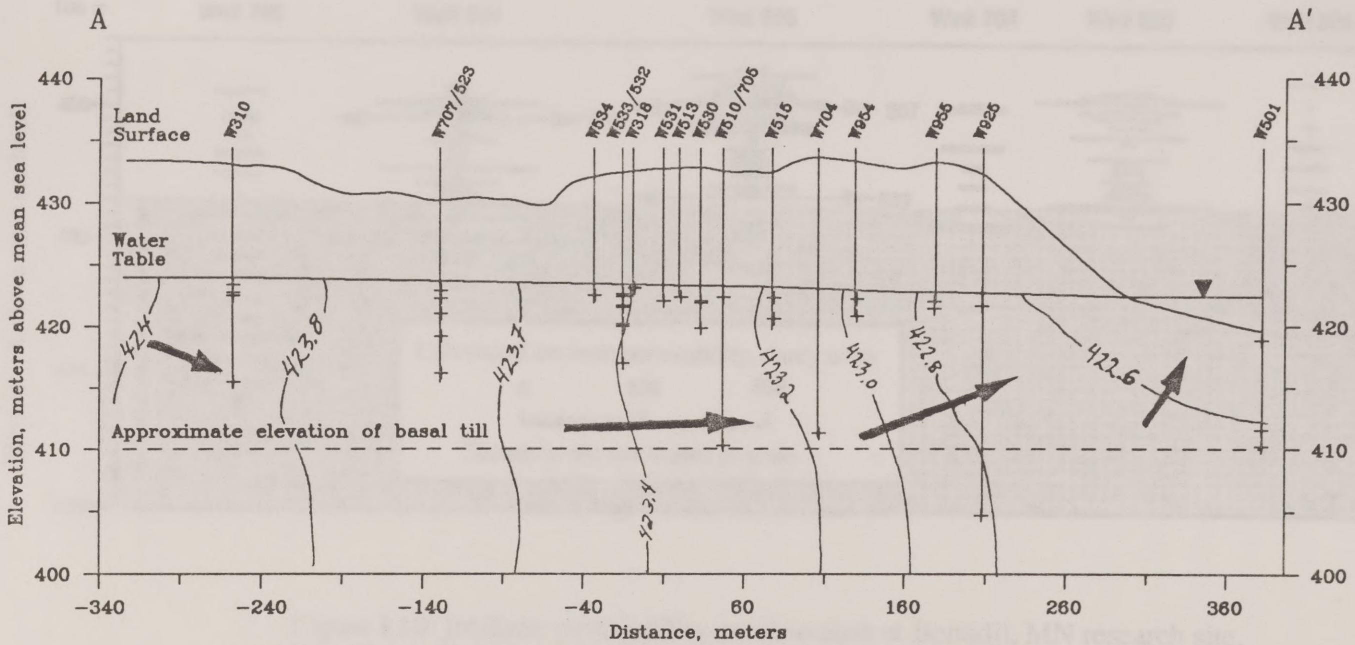


Figure I.9 Hydrogeological cross-section of site. A few of the wells along the main axis are listed above the respective well and displayed bottom screen elevations. None of these wells are water table wells. Arrows indicate flow direction. Location of cross section is shown on Figure I.1. Values along distance axis correlate with meters along cross section from the (0,0) center, used in the x-y coordinate system at the site.

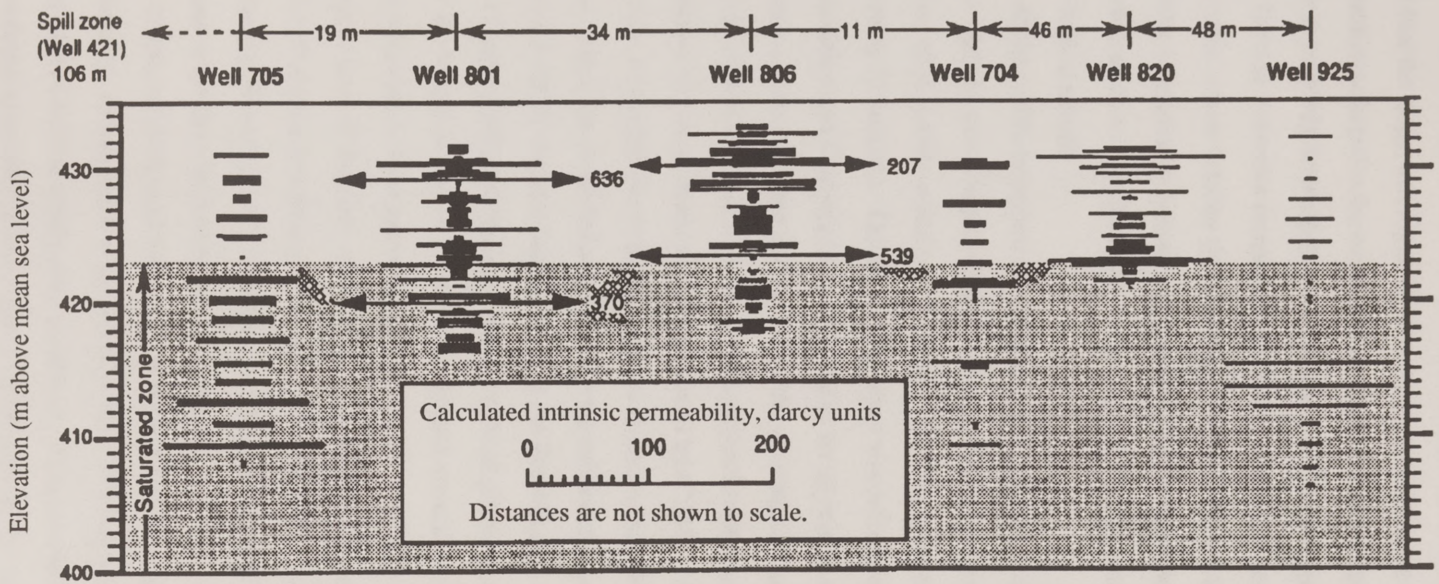


Figure I.10 Intrinsic permeability cross section at Bemidji, MN research site. See Figure II.4 for well locations. Adapted from Coontz (1991).

White (1991) determined darcian velocity variations near the northern oil plume axis and attempted simulation of contaminant transport using the measured darcian velocities. Results indicated that the major heterogeneity at the site is the silt layer located near the water table. The fine-grained layer impedes the movement of water and when near the contaminant, advancement of the plume is probably deterred to a large degree. Velocities were slowest where the silt layer was present. Darcian velocities increase with depth beneath the water table until a depth of 7 m below the water table, where velocity then decreases (White, 1991). The zone of higher hydraulic conductivity, immediately below the water table, allows for enhanced transport of contaminants. These variations in measured darcian velocity reflect the effect of the stratigraphic and hydrogeologic controls.

Miller (1988) attempted to characterize the hydrologic discontinuities and aquifer properties with the use of a groundwater flow and chemical transport model. A finite-difference method was used to study a steady-state areal and cross-sectional flow model covering approximately 55 hectares. The bottom boundary was set as a no-flow boundary, a free surface at the top boundary, and head-dependent boundaries for all other boundaries, allowing for representation of flux changes outside the model. Simulated water levels approximately matched observed water levels for 1983-85. Three-dimensional modeling had indicated that low concentrations of contaminants may have entered *lake "1386"*. Results from this study were later determined to be invalid due to incorrect initial measurements of well locations and water table elevations. Since the simulated water levels were calibrated using invalid field data, the results of the model can not be used for future studies at the Bemidji site.

Coontz (1990) determined that local vertical gradients are negligible except in the vicinity of *lake "1386"* (well location 925) where an upward vertical gradient of 0.11 was measured. Observed water levels in monitoring wells fluctuated seasonally 0.3-0.5 m during 1984-85 and were found to peak in the early summer and then decline throughout the rest of the year. Coontz (1990) determines through flow simulations that the long term flow response is dominated by the presence of *lake "1386"*. However, seasonal variations of areal recharge produce small fluctuations in the flow field near or in local depressions.

Coontz's (1990) modeling results indicated that flow patterns were independent of local surface features. Groundwater velocities of 0.065-0.143 m/d were modeled in the *spray zone* using a porosity of 0.34-0.39 in steady-state conditions. Transient-state modeling suggested the presence of two overlapping parallel plumes, one of which is presently undetected and possibly located near the pipeline. Cross-sectional steady-state simulations were used to explain a high vertical gradient in well 925, near the edge of *lake "1386"*. Modeling results suggested, but did not confirm the presence of either a continuous aquitard underneath the lake or upward flow through the basal till. Coontz's (1990) results were preliminary and based mostly on sparse data collected by others. Since the completion of Coontz (1990), several surveys have updated incorrect elevation data of wells.

Contaminant Behavior

At least two separate oil lenses are located on the water table, one below the point of the pipeline break and the other beneath the wetland area, and these have formed two separate plumes; the large northern plume, near the pipeline break, beneath the main axis of wells, and a smaller plume downgradient of the wetland. The northern oil pool is thought to contain 16-80 m^3 of crude oil (Hult, 1982), covers an area of 0.7 hectare, with dimensions of 200 m x 35 m, and depresses the water table at the center of the oil lens (Essaid et al., 1991). Essaid et al. (1991) determined that because of sediment heterogeneities, oil lens distribution in the sediment poorly corresponds with oil thicknesses measured in wells.

The northern oil pool is located at a depth of 8 m and has migrated 30 m downgradient as a separate fluid phase in the ten years since the spill (Landon and Hult, 1991). Constituents in the oil plume moved 200 m downgradient of the spill, while vapors moved 100 m through the unsaturated zone (Hult, 1989). A thin layer of oil was detected at well 604, 35 m upgradient from the pipeline break and has been interpreted as the trailing (upgradient) edge of the pool (Coontz, 1990).

The northern plume consists of chemical constituents and by-products (dissolved organic components of oil and metabolic products of biodegradation such as methane, CO^2, and organic acids), inorganic compounds, and ions mobilized from sediments (Baedecker et al., (1989), Bennett (1991), and Siegel et al., (1988)). Hult (1989) suggests that the oil pool is being depleted of volatiles and becoming more dense and viscous. Landon and Hult (1991) calculated yearly oil-mass rate loss rates of 0-1.25%, averaging 0.5%, within the oil pool.

Contoured plots of inorganic and organic solutes in the groundwater indicate variations in groundwater flow patterns (Siegel et al., 1988; Bennett et al., 1992). There are several perturbations within the contaminant plumes, indicating a heterogeneous flow field.

Figure I.11 indicates an eastward component of flow 160-180 m downgradient of the pipeline. The plume is being deflected somewhat from the northeast to the northwest, possibly resulting from local hydrogeologic conditions in the kettle area and stratigraphic differences.

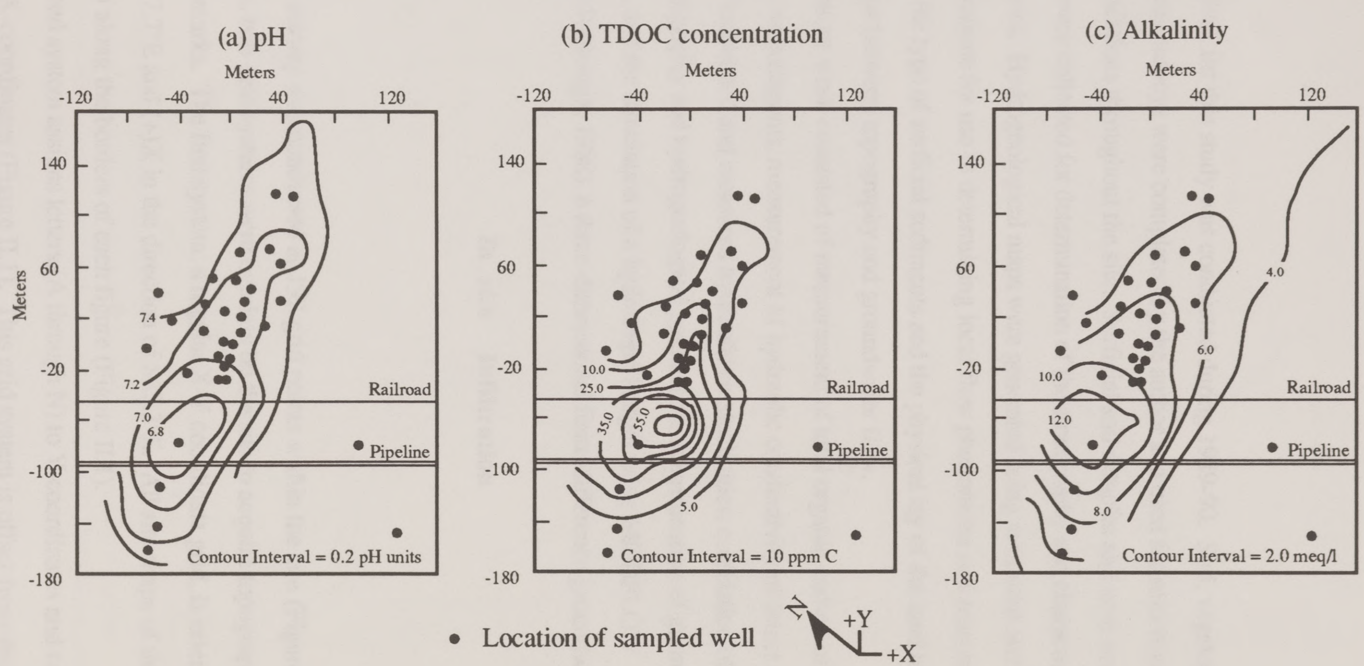


Figure I.11 Areal distributions of (a) pH, (b) TDOC concentration, and (c) alkalinity at the water table downgradient of the crude oil spill (Bennett et al, 1992).

II. METHODS OF INVESTIGATION

Fieldwork for this study was conducted during 1989-90. Soil, vegetation, and geomorphological surveys were completed by the author and used for selection of infiltration rate measurement locations throughout the site. Surficial soil samples and core sediments from newly installed wells were collected for determination of the stratigraphy and characteristics of the surficial sediments. Hydrogeological maps were generated using measured and previously collected water level elevations for use in determining local flow phenomena and seasonal responses. Characterizing the type of surficial sediments and the physical lay of the land helped determine the interrelationships between topography and groundwater flow.

Laboratory work consisted of measurement of total organic carbon of soil samples, description of core sediments, measurement of hydraulic conductivity of intact core sediments, comparisons of calculated and measured hydraulic conductivities, correlation of data to previously determined stratigraphy and hydrogeological parameters, determination of grain-size distribution of core sediments, and the simulation of a hydrologic budget using MODFLOW (McDonald and Harbaugh, 1988), a three-dimensional finite-difference groundwater flow model.

In situ Infiltration

Field Surveys

A soil survey was conducted at 193 grid points within the site (Figure II.1). Prior to the start of research, two grid systems were overlain on the site to acquire topography data and establish benchmarks. The first system, a regular X-Y coordinate grid, is oriented with (+)Y in the direction of N37.7°E and (+)X in the direction of S52.3°E. All site maps of this study indicate this first system along the borders of each figure (Figure II.1).

A second system assigns letters (A through N) to Y-coordinates and numbers ((-6) through 11) to X-coordinates (Figure II.1). This grid system is offset from the first grid

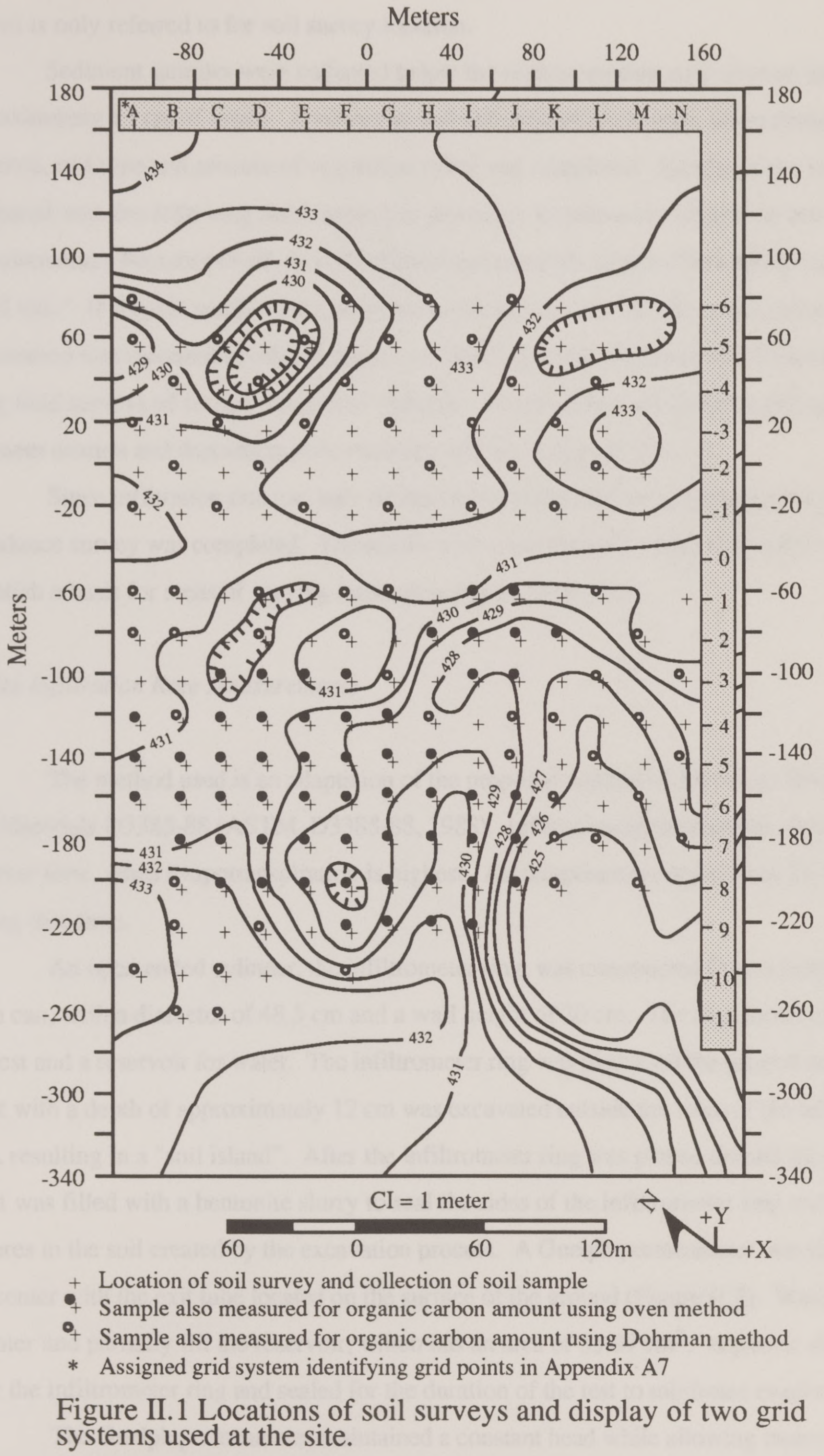


Figure II.1 Locations of soil surveys and display of two grid systems used at the site.

approximately 10 m in the X direction and a few meters in the Y direction. In this study, this system is only referred to for soil survey location.

Sediment samples were collected below the organic rooting zone over an interval of approximately 15 cm of depth. A survey of soil and ground cover type, slope amount, oil presence, and type and amount of vegetation cover was completed. Results of the survey was compared with the following field surveys to determine locations for infiltration rate measurements. Presence of oil on soil surfaces was mapped using a visual identification and a "sniff test." If the soil smelled oily, repelled water, or had a visible oil coating over the surface, the location was recorded as oily. Evidence of significant overland flow was determined visually using field surveys of surface water flow direction. Points of focused recharge and areas of sediment erosion and deposition were observed and noted on field surveys.

Since infiltration rate can vary depending on vegetation type, a vegetation type and abundance survey was completed. The results were combined with other field surveys in order to establish a basis for areas of varying infiltration and recharge rates.

In Situ Infiltration Rate Measurements

The method used is an adaptation of the proposed method of American Society for Testing and Materials D3385-88 (ASTM D3385-88, 1988). Infiltration measurements were taken in the summer time, when evapotranspiration is highest. Air temperature ranged from 21-35°C (70-95°F) during that time.

An open ended cylinder, the infiltrometer ring, was constructed from a heavy duty plastic trash can, with a diameter of 48.5 cm and a wall height of 20 cm. The ring forms a boundary for the test and a reservoir for water. The infiltrometer ring was placed on the ground surface and a moat with a depth of approximately 12 cm was excavated outside the trace of the infiltrometer ring, resulting in a "soil island". After the infiltrometer ring was placed around the soil island, the moat was filled with a bentonite slurry to seal the sides of the infiltrometer ring and any possible fissures in the soil created by the excavation process. A Guelph permeameter was then placed over the center with the exit tube located on the surface of the ground (Figure II.2). Water was allowed to enter and partially fill the reservoir, which has an area of 35.09 cm^2. A plastic sheet was placed over the infiltrometer ring and sealed for the duration of the test to minimize evaporative losses.

The Guelph permeameter maintained a constant head while allowing measurement of

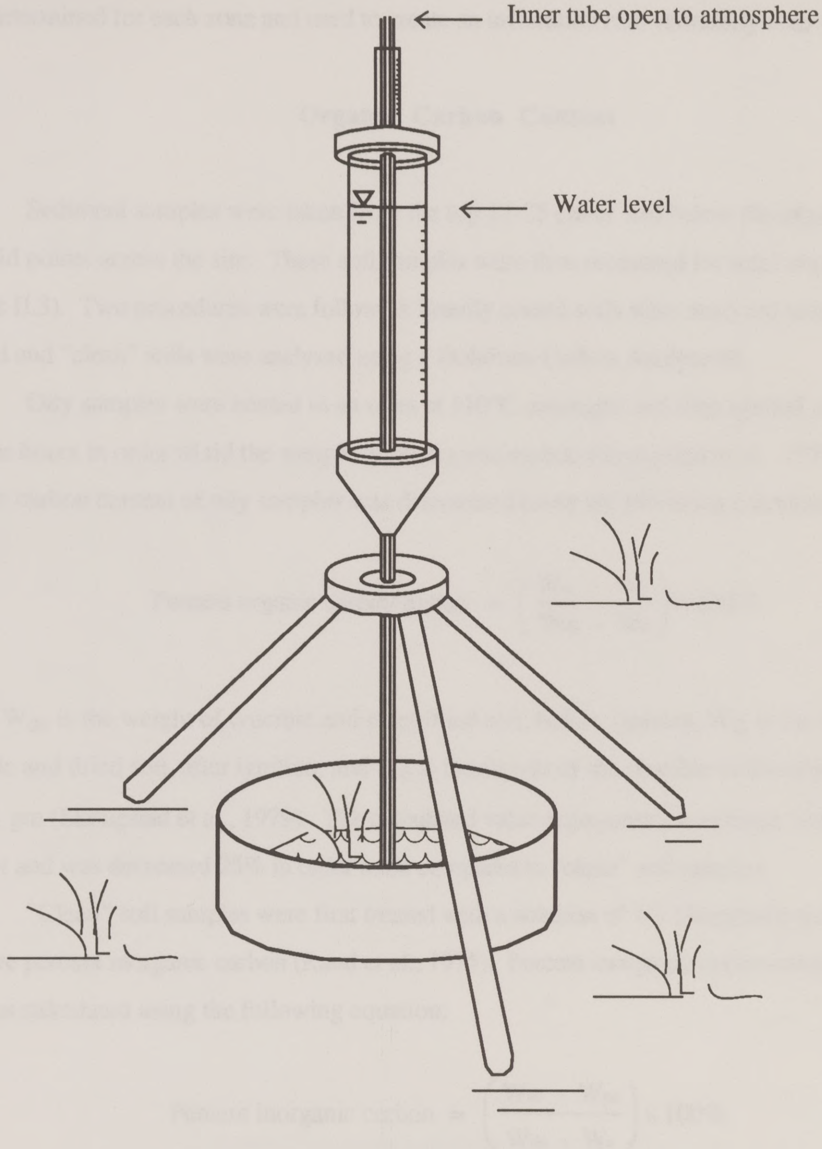


Figure II.2 Schematic of Guelph permeameter adapted for use as an infiltrometer.

infiltrated volume. Incremental infiltration rates were multiplied by the area of the reservoir in the Guelph permeameter, to calculate a volume of water loss, which in turn was divided by the area of the infiltrometer ring. The arithmetic mean, mode, and median values of resulting infiltration rates were determined for each zone and used to create an infiltration rate variability map of the site.

Organic Carbon Content

Sediment samples were taken from the top 12-25 cm of soil below the organic layer at 129 grid points across the site. These soil samples were then measured for total organic carbon (Figure II.3). Two procedures were followed; heavily coated soils were analyzed using a furnace method and "clean" soils were analyzed using a Dohrman Carbon Analyzer®.

Oily samples were heated in an oven at 110°C overnight and then ignited at 550 ± 20°C for four hours in order to rid the sample of all organic carbon (Skougstad et al., 1979). Total organic carbon content of oily samples was determined using the following calculation:

$$\text{Percent organic carbon matter} = \left(\frac{W_{ds} - W_{is}}{W_{ds} - W_c}\right) \times 100\% \qquad \text{(II.1)}$$

where W_{ds} is the weight of crucible and oven dried soil, before ignition, W_{is} is the weight of crucible and dried soil, after ignition, and W_c is the weight of the crucible to the nearest 0.0001 gm (Skougstad et al., 1979). The calculated value represents a measured "volatile" matter amount and was decreased 25% in order to be compared to "clean" soil samples.

"Clean" soil samples were first treated with a solution of 1% phosphoric acid, in order to measure percent inorganic carbon (Rand et al., 1975). Percent inorganic carbon content of "clean" soil was calculated using the following equation:

$$\text{Percent inorganic carbon} = \left(\frac{W_{ds} - W_{ps}}{W_{ds} - W_c}\right) \times 100\% \qquad \text{(II.2)}$$

where W_{ps} is the weight of the crucible and soil, dried after treatment with phosphoric acid.

A Dohrman Total Carbon Analyzer® was then used to determine total organic carbon per gm of soil. Samples were analyzed in triplicate in order to determine analytical reproducibility and sample homogeneity.

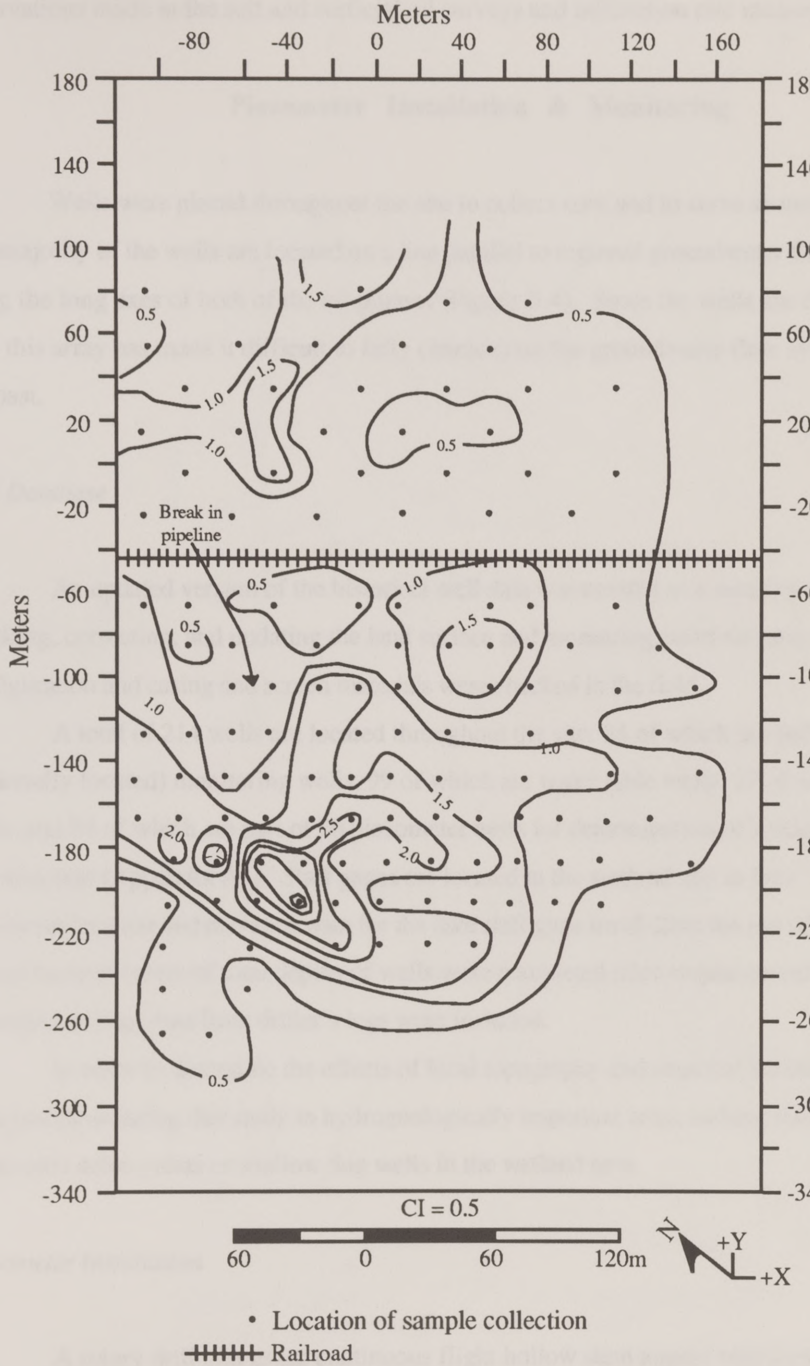


Figure II.3 Percent organic carbon by weight of surficial soils

All sample means were compared, mapped, and contoured. Results were compared with observations made in the soil and surficial oil surveys and infiltration rate measurements.

Piezometer Installation & Monitoring

Wells were placed throughout the site to collect core and to serve as monitoring wells. The majority of the wells are located on a line parallel to regional groundwater flow direction and along the long axes of both of the oil plumes (Figure II.4). Since the wells are clustered along a line, this array has made it difficult to fully characterize the groundwater flow system at the site in the past.

Well Database

An updated version of the historical well data was created as a result of collecting, checking, correcting, and updating the land surface and measuring point elevations of wells. Well configuration and casing and screen materials were checked in the field.

A total of 214 wells are located throughout the site: 34 of which are background (regionally located) monitoring wells, 99 of which are water table wells, 13 of which are soil gas wells, and 84 of which are part of 26 piezometer nests for determination of vertical flow presence and direction (Appendix A1). Staff gages are located in the wetland and in *lake "1386"*, but inaccurate location and elevation data for the lake staff gage invalidates the use of collected data. Actual measurements of total depths of wells were completed after emplacement of most wells. Historical drilling data from driller's logs were included.

In order to determine the effects of local topography and seasonal variations, 17 wells were installed during this study in hydrogeologically important areas lacking data. Ten of these wells were drive points or shallow dug wells in the wetland area.

Piezometer Installation

A rotary drill unit using continuous flight hollow stem augers was used for all well installations. A 1.5 m piston core barrel collected core samples. Appendix A2 contains logs of the cores collected during this study. 98 wells are constructed with polyvinyl chloride (PVC)

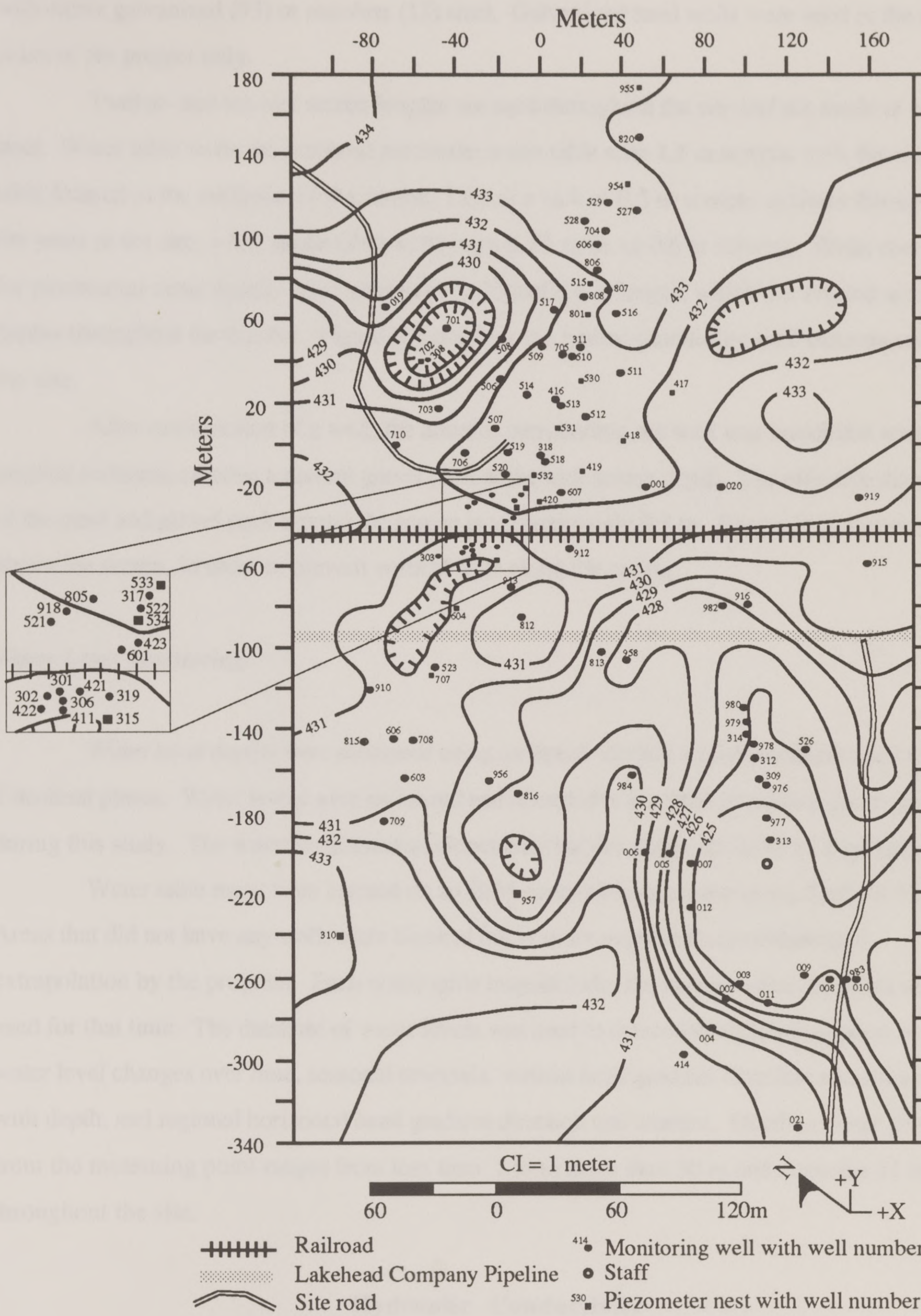


Figure II.4 Well locations at the Bemidji, Minnesota research site.

casing and protected at the surface with black steel well protectors; the rest of the wells are made with either galvanized (93) or stainless (13) steel. Galvanized steel wells were used in the early years of the project only.

Twelve- and ten-slot screen lengths are used throughout the site and are made of stainless steel. Water table wells are screened across the water table with 1.5 m screens with the water table located at the midpoint of the screen. Due to a lack of 0.5 m screens at times throughout the years at the site, a few water table wells have 0.15, 0.46, or 0.6 m screens. Wells constructed for piezometer nests usually have screens of 0.15 and 0.6 m length, which are located at varying depths throughout the aquifer. Figure II.5 displays the typical monitoring well constructed at the site.

After construction of a well, the annulus surrounding the well was backfilled with the original sediment creating a natural gravel pack at the well screen depth. The effective diameter of the sand and gravel pack around the screen is approximately 0.3 m. Bentonite was then placed above the screen, in order to prevent vertical flow along the casing.

Water Level Monitoring

Water level depths were measured using an Epic® electric sounder with an accuracy of 3 decimal places. Water levels were measured and recorded at irregular intervals prior to and during this study. The water level measurements used for this study are listed in Appendix A3.

Water table maps were created on an IBM compatible computer using Surfer® 4.04. Areas that did not have any wells were blanked out in order to prevent unsubstantiated extrapolation by the program. Each water table map includes the numbers and locations of well used for that time. The database of water levels was used to determine such information as water level changes over time, seasonal reversals, vertical head gradient direction and amount with depth, and regional horizontal head gradient direction and amount. Depth to water level from the measuring point ranges from less than 1 m to more than 30 m and averages 11 m throughout the site.

Hydraulic Conductivity

Sediment cores were collected in the field, in clear butyrate liners, sealed to maintain

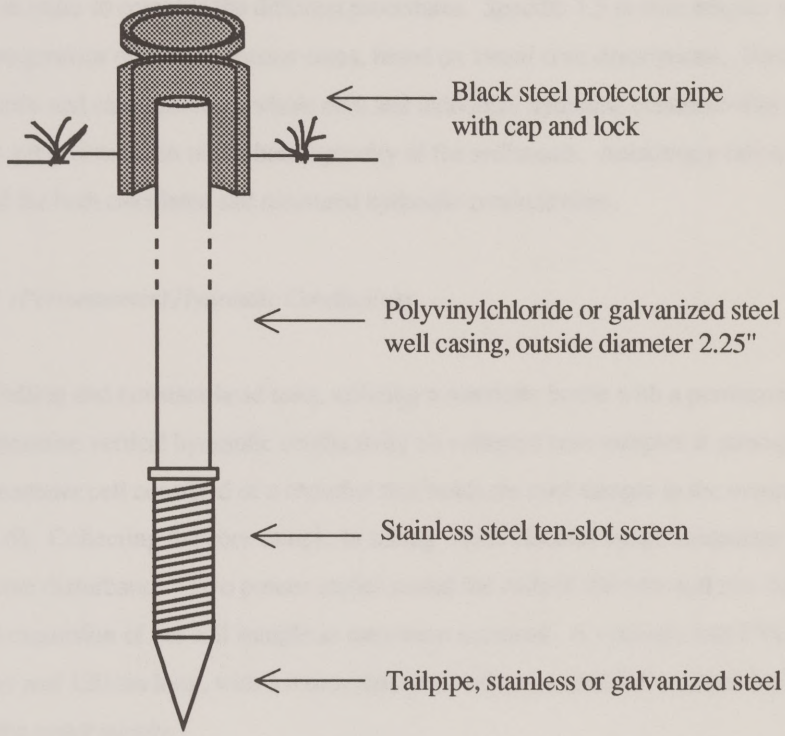


Figure II.5 Typical well construction at the Bemidji, MN research site, not to scale.

moisture, and then transported to the laboratory where they were described, analyzed for location of particle-size analysis, and measured for whole core hydraulic conductivity. The cores were then frozen and cut into sections for further analyses of effective grain diameter and measured hydraulic conductivities of individual cores. Effective grain diameter was used in determination of calculated hydraulic conductivities. Measured and calculated hydraulic conductivities for each sample were compared in order to compare the different procedures. Specific 1.5 m core lengths were labeled as either homogeneous or heterogeneous cores, based on visual core descriptions. Resulting measurements and calculations of whole core and individual hydraulic conductivities were compared in order to get a better idea of the heterogeneity of the sediments. Anisotropy ratios were determined for both calculated and measured hydraulic conductivities.

Measured (Permeameter) Hydraulic Conductivity

Falling and constant head tests, utilizing a marriotte bottle with a permeameter cell, were used to determine vertical hydraulic conductivity on collected core samples at atmospheric pressure. The permeameter cell consisted of a chamber that holds the core sample in the original core sleeve (Figure II.6). Collecting the core sample in tubing which fits into the permeameter allowed for minimal core disturbance. Two porous stones sealed the ends of the core and two rubber gaskets prevented expansion of the soil sample as saturation occurred. A vertical clear PVC tube, 3.8 cm in diameter and 120 cm long, with a removable inner tube was used for constant head tests and provided the water supply.

The method used for the constant head test conformed to ASTM D2434-68 (ASTM D2434-68, 1968). It is assumed that Darcy's law is valid and the hydraulic gradient is essentially unaffected by hydraulic losses. The rate of flow was kept sufficiently small so that disturbance of grains was minimal. Measurements for determination of hydraulic conductivity were taken as soon as the sample was saturated and no leaks or trapped air throughout the system were detected. Sample measurements were repeated until the measured hydraulic conductivities were repeated within 5% accuracy. The majority of the samples were run 3 or more times, however, a few cores with very low hydraulic conductivities were discontinued after two runs. These particular cores would take several days to a week to saturate let alone produce a repeatable value.

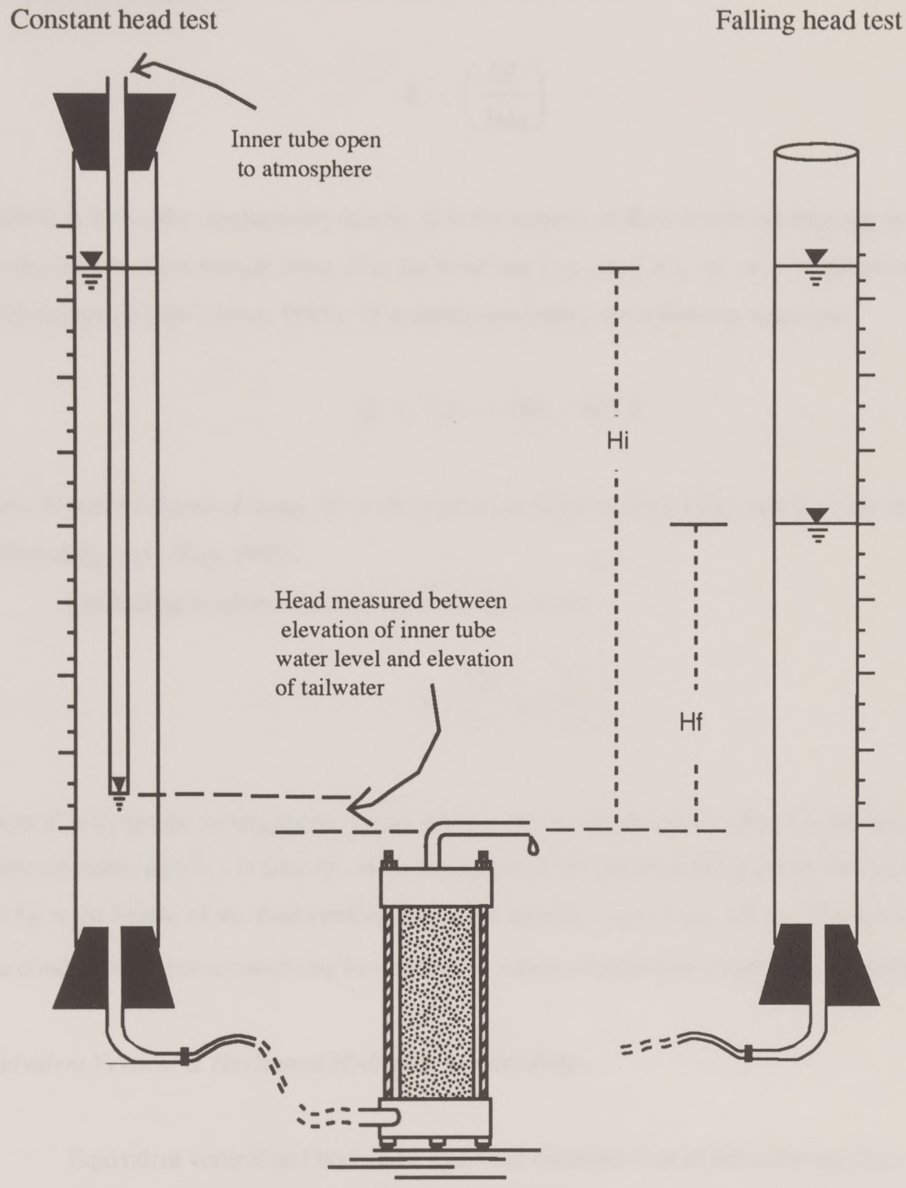


Figure II.6 Schematic of marriotte bottle with permeameter cell.
Adapted from Olson and Daniel, 1981.

The constant head test evaluates the hydraulic conductivity of samples that consist of mostly sands and gravels. The equation that evaluates flow is:

$$K = \left(\frac{QL}{HAt}\right) \quad \text{(II.3)}$$

where K is hydraulic conductivity (cm/s), Q is the volume of flow (cm^3) discharging in time, t (s), *L* is the length of the sample (cm), H is the head loss (cm), and *A* is the area of the marriotte bottle apparatus (cm^2) (Das, 1985). Q is determined using the following equation:

$$Q = VA = (Rf - Ri)\,A \quad \text{(II.4)}$$

where V is the volume of water, Rf is the final water level reading (cm), and Ri is the initial water level reading (cm) (Das, 1985).

The falling head test uses the following equation:

$$K = \left(\frac{aL}{At}\right)\ln\left(\frac{Hi}{Hf}\right) \quad \text{(II.5)}$$

where K is hydraulic conductivity (cm/s), a is the area of the sample (cm^2), *A* is the area of the marriotte bottle (cm^2), t is time (s), H_i is the height of the initial reading above the tailwater (cm), and H_f is the height of the final reading above the tailwater (cm) (Das, 1985). The falling head test was conducted on cores containing low estimated values of grain-size and hydraulic conductivity.

Equivalent Vertical & Horizontal Hydraulic Conductivity

Equivalent vertical and horizontal hydraulic conductivities of the collected cores were calculated from values of hydraulic conductivities measured in the lab and calculated from grain-size data.

The following equations from Leonards (1962) were used in calculations;

$$Kx = \left[\frac{\Sigma(ziKi)}{\Sigma zi} \right] \qquad Kz = \left[\frac{\Sigma zi}{\Sigma\left(\frac{zi}{Ki}\right)} \right] \tag{II.6}$$

where K_x is the equivalent horizontal hydraulic conductivity (cm/s) for a vertical section, K_z is the equivalent vertical hydraulic conductivity (cm/s), z_i is the thickness of the layer (cm), and K_i (cm/s) is the homogeneous hydraulic conductivity for an individual layer. When K_x does not equal K_z, the aquifer is anisotropic.

Anisotropy ratios of equivalent hydraulic conductivities were calculated using the following equation:

$$\text{Anisotropy ratio} = \left(\frac{Kx}{Kz} \right) \tag{II.7}$$

Calculated (Hazen's) Hydraulic Conductivity

Grain-size is related to pore sizes, hence the relationship to permeability. Hazen (1911) proposed that the permeability of a porous rock is proportional to the square of a mean diameter and a value that represents the distribution of the grain-sizes in a sample. Hazen's approximation is shown below;

$$K = \left(Cd_{10}\right)^2 \tag{II.8}$$

where K is the hydraulic conductivity (cm/s), *C* is a constant that varies from 100 to 150 for loose sands ($cm^{-1}s^{-1}$), and d_{10} is the effective grain diameter (cm) where 10 percent of particles passing are finer. A value of 100 ($cm^{-1}s^{-1}$) for the *C* value was assigned to all samples. These calculated values were then compared to the measured hydraulic conductivity at the same depth interval.

Grain-size distribution of the collected core sediments was determined using the dry-sieve analysis suggested by Folk (1974). The grain-size classification by Udden-Wentworth (1922) was followed for this study. Principal groups are as follows:

gravel	> 2 mm
sand	2 - 0.0625 mm
silt	0.0625 - 0.0039 mm
clay	< 0.0039 mm

The sample were sieved for 10 minutes using a Ro-Tap shaker. Loss of sample was less than 3%. Individual sieves and the respective contents were weighed to the nearest 0.01 gm. Sieve openings on a log scale were used for most sediments, however on a few of the smaller size fraction samples, the sieves were not chosen logarithmically due to problems with equipment availability. The value for d_{10}, the effective grain diameter, was graphically determined on a log scale graph of percent finer passing versus grain-size.

Numerical Flow Model

Two phases of modeling are introduced with a short description of their importance. A more detailed description of the followed methods, results, discussion, and conclusions of each phase are given in the section under the heading "GROUNDWATER MODELING".

Theory

MODFLOW is a U. S. Geological Survey finite-difference ground-water flow model written in FORTRAN 77 that simulates groundwater flow in both two- and three-dimensions (McDonald and Harbaugh, 1988). MODFLOW aids in the understanding of flow systems, hydrologic budgets, and hydraulic properties of hydrogeological units. The model consists of several packages for simulation of areal recharge, wells, drains, streams, evapotranspiration, and various boundary conditions that deal with a specific feature of the hydrologic system. This system allows for the effects of each specific feature to be examined independently.

Finite-difference equations are solved through iteration of a strongly implicit procedure at specified time steps on the following equation;

$$\frac{\partial h}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial h}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial h}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)=Ss\left(\frac{\partial h}{\partial y}\right)+W \qquad \text{(II.9)}$$

where x, y, and z are cartesian coordinates parallel to major axes of the flow system, K_{xx}, K_{yy}, and K_{zz} are hydraulic conductivities in the x, y, and z directions (m/s), respectively, h is the hydraulic head (m), S_s is the specific storage (m^{-1}), t is time (s), and W is the volumetric flux per unit volume (s^{-1}). This equation is valid assuming darcian flow is due solely to a gradient based on boundary conditions. W represents a source or sink of water such as evapotranspiration or recharge. The volumetric flux term represents recharge at the upper surface of the model, discharge along the prescribed head boundary, discharge to wells, and leakage between surficial aquifer and underlying bedrock. Groundwater flow is simulated using a block centered finite-difference method.

Model plan

The initial phase of steady-state modeling incorporated data collected from the field and compared simulated results with observed results as part of the calibration of the starting model. The steady-state areal model generated flowpaths under the assumptions of constant recharge and evapotranspiration in an isotropic and heterogeneous aquifer with fixed boundaries through time. A sensitivity analysis of the steady-state model involved testing time-constant aquifer and model parameters. Results were used to better define the model before simulations with time-varying parameters. These conditions were tested under more realistic conditions by simulating the effect of seasonal variations in recharge and evapotranspiration. Detailed description of steps taken and the associated results are presented and discussed in a later section.

III. RESULTS

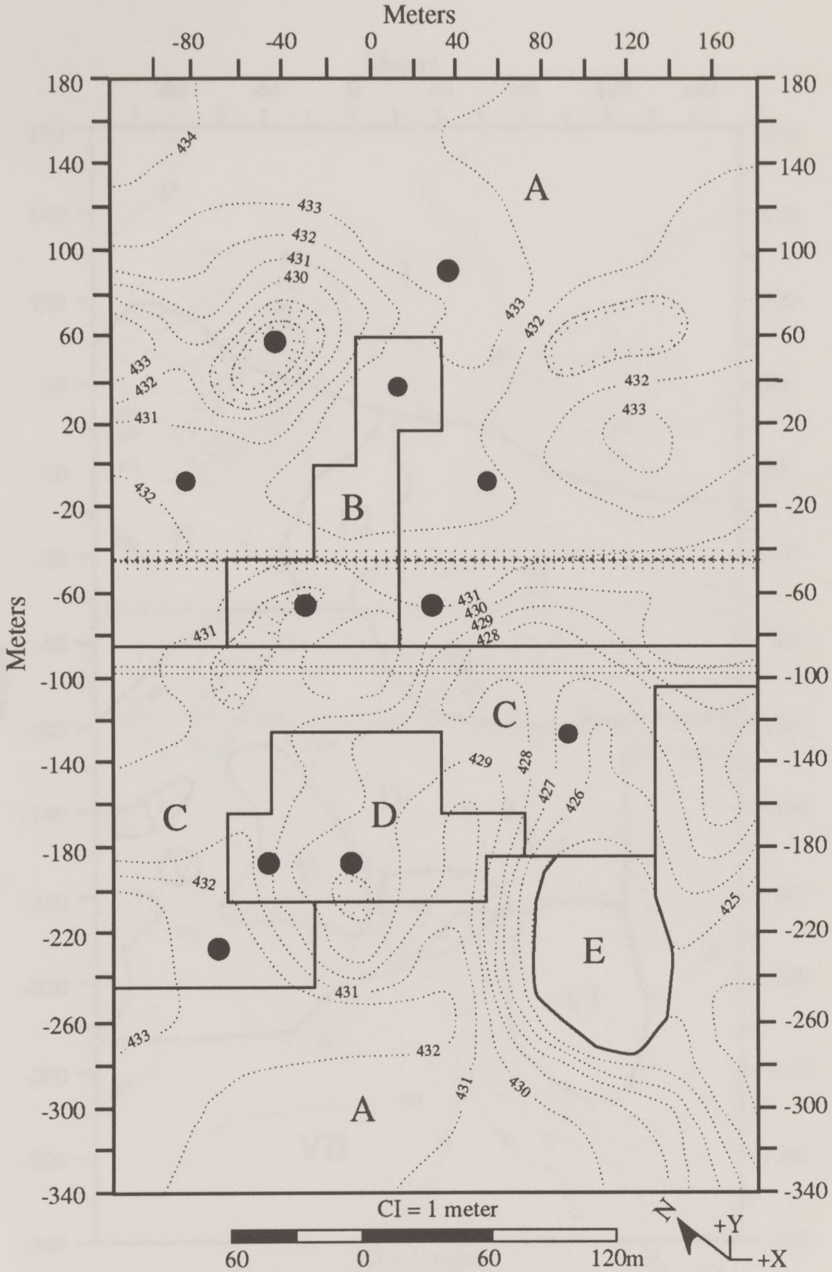
In situ Infiltration

A study of the field surveys resulted in the location of representative zones to be measured for infiltration rates (Figure III.1). These zones have varying vegetation type and amount, presence or lack of oil on surficial sediments, depositional or erosional areas, slope, and soil type that effect infiltration rate. The extent of the zone boundaries, associated range of areal recharge rate, and the assigned weighted value for modeling purposes is indicated on the diagram. Distribution of the location of *in situ* measurements is shown. Results of *in situ* incremental infiltration velocities are displayed in Appendix A6. Distinctive vegetative zones are shown in Figure III.2 and described in Table III.1, oil presence on surficial sediments is mapped in Figure III.3, and surface water behavior (depositional and erosional areas) are mapped in Figure III.4. Appendix A7 lists the results of the soil survey.

Surface Conditions

Infiltration zone A is highly vegetated with dense 6-15 m pine trees of up to 40 cm in diameter, aspens, oaks, shrubs, grasses, bushes, moss, and ferns (Figures III.1; Figure III.2; Table III.1). Fallen dead trees are strewn throughout the ground cover. The slope in this area is a relatively small, except in the kettle area. *In situ* measurements were taken at well locations 605 and 701 and grid locations H1, B(-2), and I(-2). This zone has infiltration rates in the range of 6.3-13.1 m/d with a mean of 9.03 m/d, median of 8.74 m/d, and mode of 8.74 m/d. Zone A was assigned a value of 9.03 m/d and weight factor of *high* for modeling purposes.

Infiltration zone B consists of a thin cover of grasses and a few pines less than 6 m in height. Topography is of a fairly level plain that receives most of the human and machinery traffic a the site. In situ measurements were taken at grid locations E1 and G(-4) (Figure III.1). Values range from 2.9-5.4 m/d with a mean of 3.79 m/d, median of 3.6 m/d, and mode of 3.6 m/d.



Zone	Range (m/d)	Mean	Weight factor
A	6.3-13.1	9.03	High
B	2.9-5.4	3.79	Low
C	4.3-7	5.79	Medium
D	0-0.07	0	0
E	Infinite recharge		

Lakehead Company Pipeline
Railroad
Elevation contour lines, m above mean sea level
Location of field infiltration measurements

Figure III.1 Infiltration rates and zones at the site

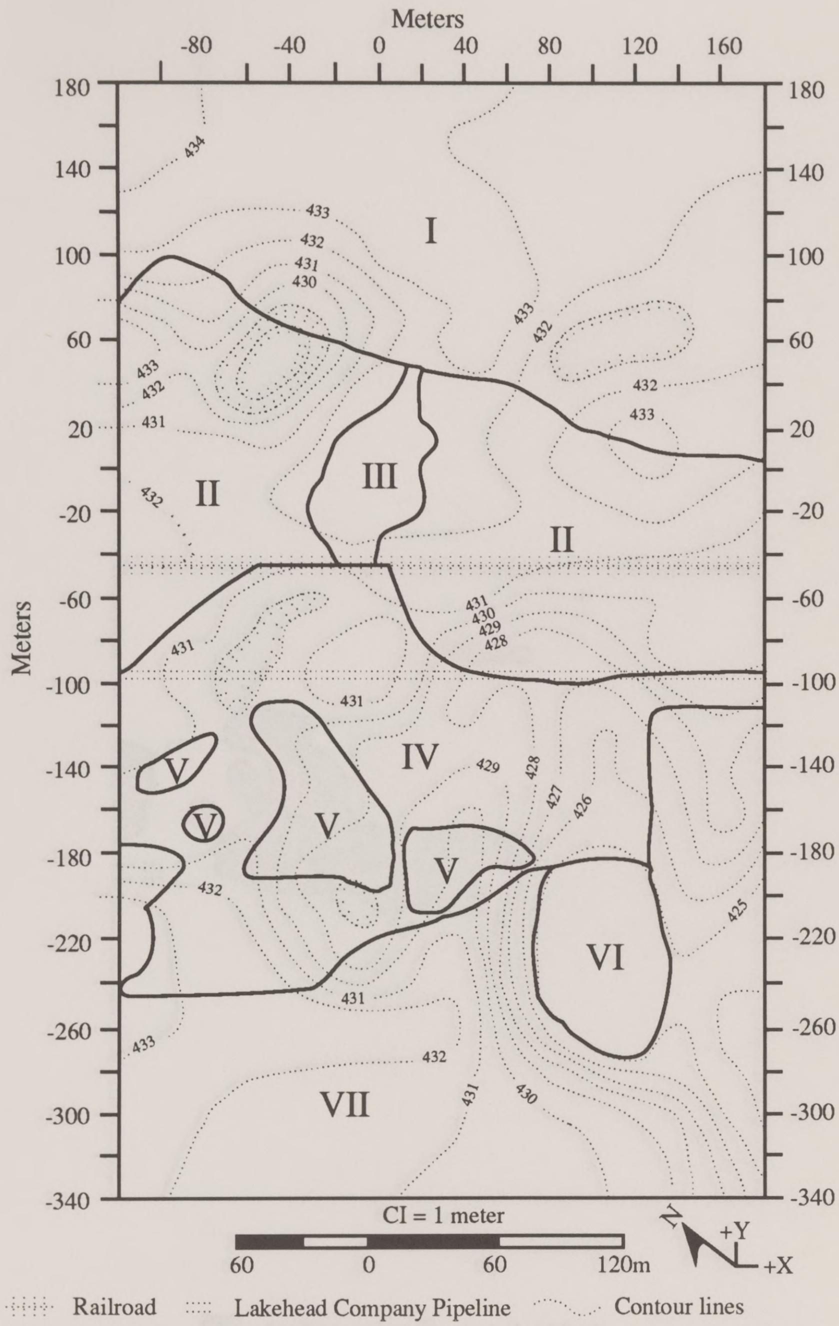


Figure III.2 Vegetation type, location, and abundance at study site. An explanation of vegetation zones is in Table III.1

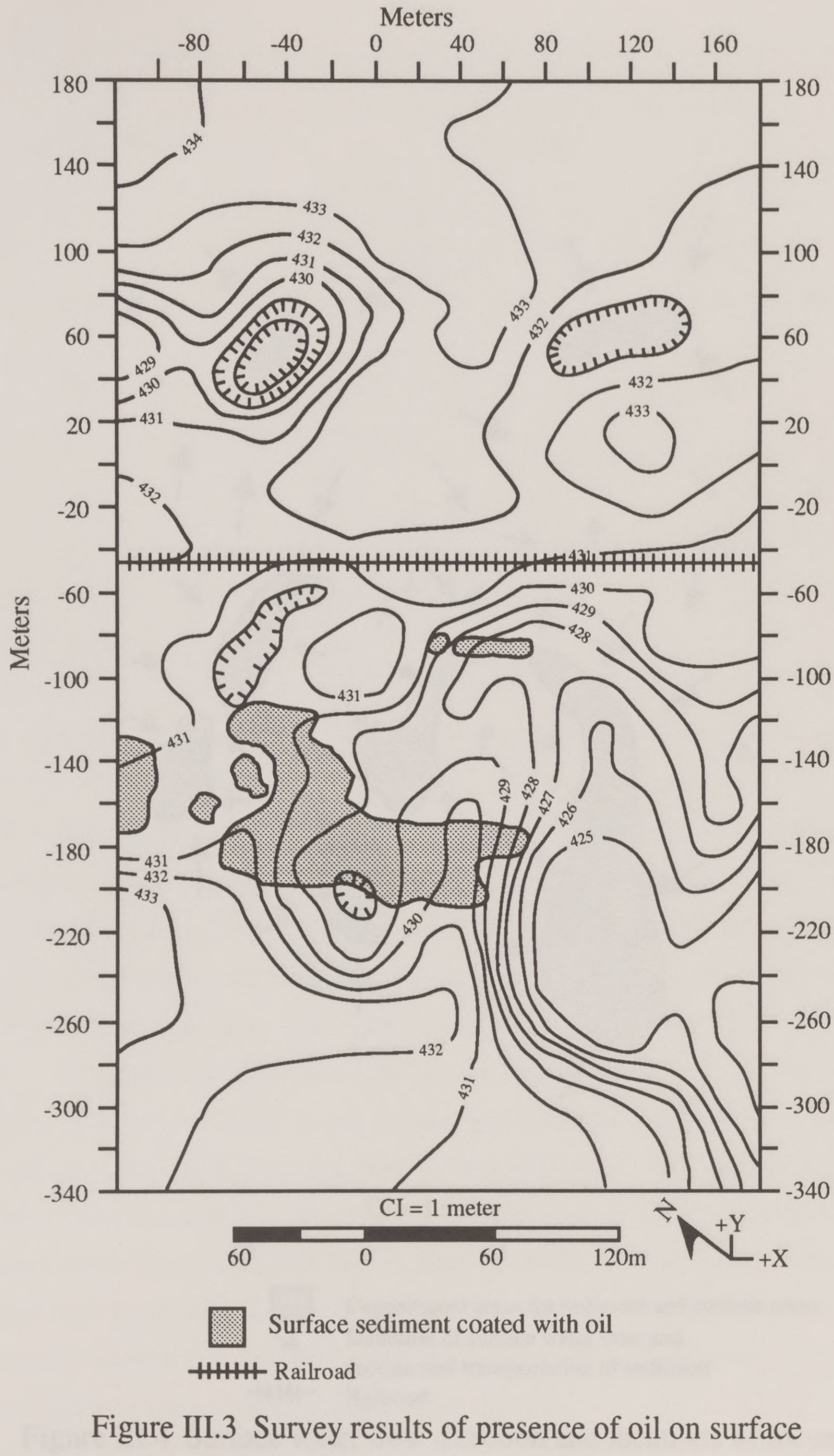


Figure III.3 Survey results of presence of oil on surface

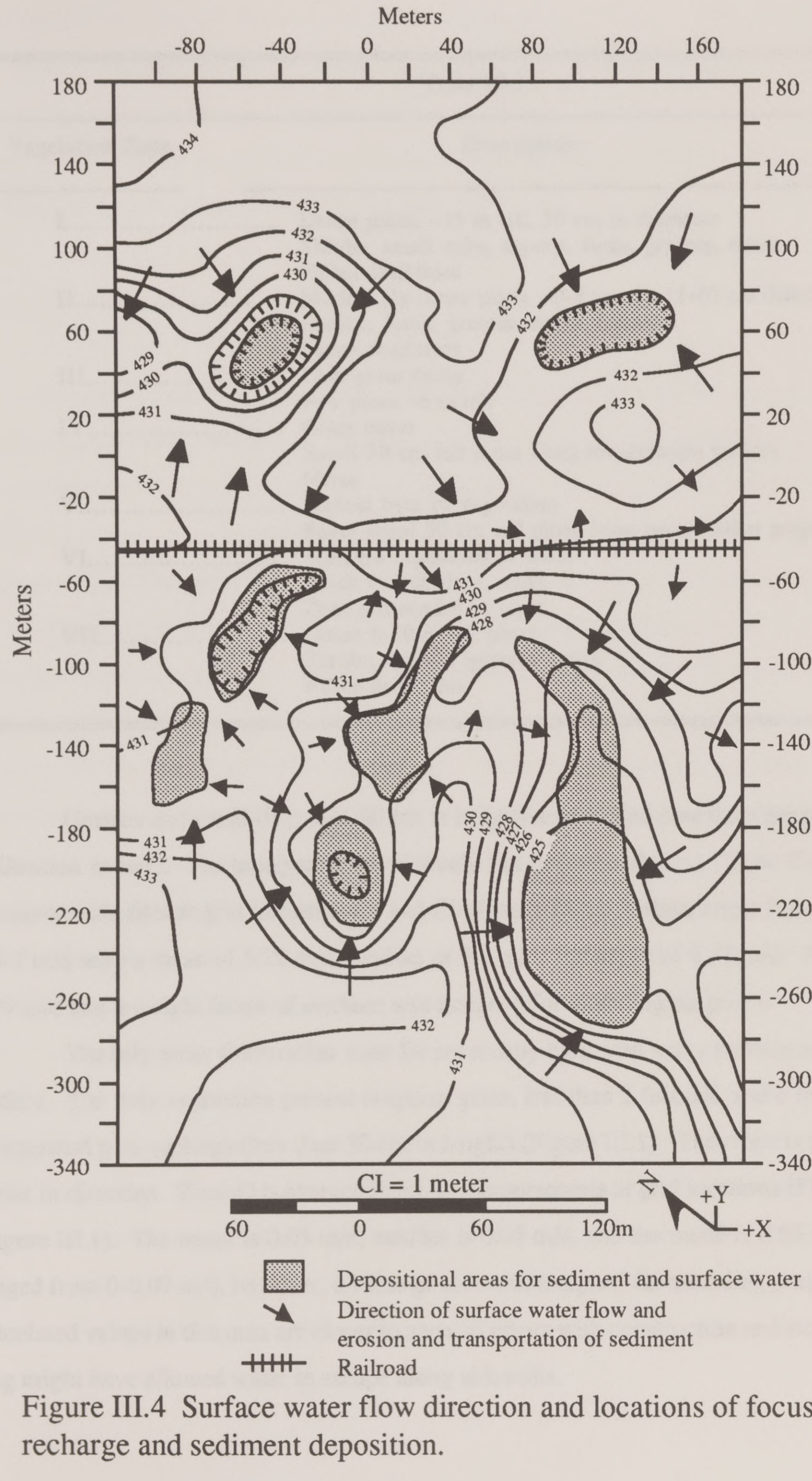


Figure III.4 Surface water flow direction and locations of focused recharge and sediment deposition.

A value of 3.79 m/d and a weight factor of *low* was applied for modeling purposes.

Table III.1

Vegetation Zone	Description
I	Dense pines, ~15 m tall, 30 cm in diameter Shrubs, small oaks, aspens, ferns, grasses, moss Fallen dead trees
II	Moderately dense pines, ~3-8 m tall, 11-40 cm diameter Shrubs, ferns, grasses, moss, lichens Fallen dead trees
III	Thin grass cover Few pines ~6 m tall
IV	Grass cover Small 50 cm tall pines from revegetation project Moss
V	Almost bare of vegetation Some small 50 cm tall pines from revegetation project
VI	Wetland vegetation in water Thick bed of grass, moss Zone surrounded by trees
VII	Dense 6-10 m tall pines Shrubs, aspens, grasses, moss Fallen dead trees

Grasses and small (less than 50 cm in height) revegetated pine trees are present in infiltration zone C. The topography is relatively flat to gently sloping. Zone C contains two measurements sites at grid locations K4 and C9 (Figure III.1). Values range from 4.3-7 m/d with a mean of 5.79 m/d, median of 5.9 m/d, and mode of 6.53 m/d. A value of 5.79 m/d and a weight factor of *medium* was assigned for modeling purposes.

The oily areas (infiltration zone D) are mostly bare with many pebbles and cobbles on the surface. The only vegetation present is sparse grass, less than 2 feet tall, and a few small revegetated pine saplings (less than 50 cm in height) (Figure III.1). The slope is moderate and varies in direction. Zone D is characterized by measurements at grid locations D7 and F7 (Figure III.1). The mean is 0.05 m/d, median is 0.05 m/d, and the mode is 0.05 m/d. Values ranged from 0-0.07 m/d, however, a value of zero was assigned for modeling purposes. The calculated values in this area are closer to zero, as errors with construction and emplacement of the ring might have allowed water to escape along sidewalls.

In the wetland area (infiltration zone E) vegetation consists of mostly grass and moss and are growing year round in saturated sediments. The edges of the wetland area are lined with trees. Since water creates the surface in this area, the slope is flat. Surrounding the wetland, the ground surface slopes at a moderate to high angle into the wetland. This zone was not measured for *in situ* infiltration rate, as it is a water surface and is characterized by infinite recharge. Rainfall that falls over that area directly recharges the groundwater.

Surface Processes

Infiltration rates are high in both the lush forest and grassy dry soil covered areas, however, rates in the barren or less vegetated area (*spray zone*) were significantly lower. Surficial soils in areas receiving human and machinery traffic (Zone B) are compacted and subjected to break up of surface structure. Compaction has created tighter soils and possibly closed some vertical paths for gravity flow, creating lower infiltration rates than in the undisturbed neighboring areas.

Overland flow and erosion in the *spray zone* during a precipitation event was observed after only 10 min of a light rain. Water does not infiltrate, but pools on the surface and flows downslope as sheet flow over the impermeable oily surficial sediments. The majority of surface water flows to the south-southwest and infiltrates into soil near the wetland and at well 957. A smaller amount of surface water flows to the northwest and infiltrates into the soil in a small depression. Channels of water transport sediment and eventually deposit it in lower lying areas on top of previously deposited sediments which overly previously clean soil. This forms thick oily sand bodies on top of clean permeable soil. Highly contaminated water pooling up on the sand has been measured to have a dissolved organic carbon greater than 200 ppm (Bennett, personal communication, 1991).

Water pools up on top of the oily sediments. If the precipitation amount is high enough, the water flows over the oily sand, possibly recharging into the aquifer. Recharge of this contaminated water into the aquifer would be sporadic and dependent on the rainfall event and temperature conditions. If the precipitation event is short or of low rate, the fluid will most likely evaporate before it has a chance to transport sediment or infiltrate into the soil. This is especially true when the temperatures are high in the summer.

Organic Carbon Content

Analyses of 57 oily samples resulted in an average of 1.674% organic carbon by weight with a standard deviation of 0.71%. Values range from 0.52 to 4.024% organic carbon, with a median of 1.69% organic carbon by weight. Results are displayed in Appendix A8.1.

Analyses of 70 non-oily samples resulted in an average of 0.76% organic carbon by weight. Values range from 0.13 to 2.06% organic carbon with a median of 0.68% and standard deviation of 0.36%. Results are displayed in Appendix A8.2.

Figure II.3 displays the contoured values of percent organic carbon by weight and the distribution of sample locations. Most of the site soil contains 0-1.5% organic carbon by weight, however, in the south-central portion of the site there are higher values ranging from 2-4% organic carbon by weight. This area is within the *spray zone* where the oil sprayed and drained and was expected to contain sediments with high percent organic carbon. Soils containing higher percent organic carbon are located in depositional areas within the *spray zone*. Percent organic carbon decreases uphill and away from these depositional centers. A pattern similar to the path of drained oil is seen in the contoured values of percent organic carbon (Figure II.3; Figure III.4).

A small isolated area having oil on the surface (X=40 m and Y=-80 m in Figure II.3) range from 1 to 2% organic carbon by weight. This location was a topographic low in the path of draining oil toward the wetland, which retained a significant amount of crude oil. Bennett (personal communication, 1991) determined that groundwater in a nearby well (well 982) contained free products. It is possible that the oil on the surface at this location provides a source for groundwater contamination seen in nearby wells.

Particle-Size Analysis

Appendix A4 lists the results of particle-size analysis completed on 103 core samples. Percent sample loss or gain was less than 5% for all samples. Values of d_{10}, effective grain diameter, are listed in Table III.2 and Appendices A4 and A5.

Figure III.5 displays the range and average grain-size distribution curves determined from grain-size analysis of 103 core samples from my collected cores. Grain sizes vary from silts to gravel, but are mostly in the sand size fraction. Values of d_{10} ranged from 0.038 to 0.37 mm with a mean of 0.16 , median of 0.18, and standard deviation of 0.06 mm. The average grain

Table III.2 Hydraulic conductivity from grain-size and permeameter analysis

Well Number	Core Depth	Values from particle-size measurements						Values from permeameter measurements				
		Grain size d10 (mm)	Hazen's Hydraulic Conductivity C*d10 (C=100) (m/sec)	Intrinsic Permeability ki (cm2)	Equivalent Vertical Hydraulic Conductivity Kh (m/sec)	Equivalent Horizontal Hydraulic Conductivity Kz (m/sec)	Anisotropy Ratio Kh/Kz	Hydraulic Conductivity K (m/sec)	Intrinsic Permeability ki (cm2)	Equivalent Vertical Hydraulic Conductivity Kh (m/sec)	Equivalent Horizontal Hydraulic Conductivity Kz (m/sec)	Anisotropy Ratio Kh/Kz
702C	1'2.5" - 4'8"				5.00E-04	5.01E-04	1.0	2.17E-05	2.49E-08			
702C	1'2" - 3'2"	0.23	5.29E-04	6.07E-07								
702C	3'1" - 4'8"	0.22	4.84E-04	5.55E-07								
702C	5' - 6'1.5"	0.18	3.24E-04	3.72E-07				2.37E-05	2.72E-08			
702C	11'8" - 14'2.5"				1.15E-04	2.11E-04	1.8	2.44E-05	2.80E-08			
702C	10'1" - 10'9"	0.12	1.44E-04	1.65E-07								
702C	10'9" - 11'3"	0.06	3.60E-05	4.13E-08								
702C	11'7.5" - 12'	0.105	1.10E-04	1.26E-07								
702C	12' - 12'5.25"	0.2	4.00E-04	4.59E-07								
702C	12'5.25" - 13'	0.1	1.00E-04	1.15E-07								
702C	13' - 13'6"	0.12	1.44E-04	1.65E-07								
702C	13'6" - 14'4.5"	0.205	4.20E-04	4.82E-07								
702C	15'1.5" - 19'6"				1.25E-04	1.25E-04	1.0	8.30E-07	9.52E-10	3.07E-06	5.05E-06	1.6
702C	15'2" - 15'11.5"	0.12	1.44E-04	1.65E-07				3.25E-06	3.73E-09			
702C	16'0.5" - 18'	0.11	1.21E-04	1.39E-07				1.98E-06	2.27E-09			
702C	18' - 19'6"	0.11	1.21E-04	1.39E-07				1.00E-05	1.15E-08			
702C	20'1.5" - 24'5"				3.27E-04	3.79E-04	1.2	1.22E-04	1.40E-07	1.15E-04	1.45E-04	1.3
702C	20'1.5" - 20'11.75"	0.13	1.69E-04	1.94E-07				5.22E-05	5.99E-08			
702C	21'0.25" - 21'11.5"	0.22	4.84E-04	5.55E-07				1.96E-04	2.25E-07			
702C	22'0.25" - 22'11.75"	0.2	4.00E-04	4.59E-07				1.67E-04	1.92E-07			
702C	23'0.25" - 23'11.75"	0.205	4.20E-04	4.82E-07				1.43E-04	1.64E-07			
702C	24'0.75" - 24'5"	0.205	4.20E-04	4.82E-07				1.74E-04	2.00E-07			
980	1'1.25" - 4'7.75"				3.29E-04	1.66E-04	0.5	1.40E-04	1.61E-07			
980	2'5.25" - 3'3.75"	0.16	2.56E-04	2.94E-07				3.82E-05	4.38E-08			
980	3'4" - 4'8"	0.2	4.00E-04	4.59E-07								
981	1' - 3'4"							1.88E-04	2.16E-07			
981	1' - 2'7"	0.21	4.41E-04	5.06E-07								
982	1'2.5" - 3'10"				3.58E-04	3.82E-04	1.1	1.13E-04	1.30E-07			
982	1'2.5" - 2'	0.16	2.56E-04	2.94E-07								
982	2'0.5" - 2'11.75"	0.2	4.00E-04	4.59E-07				3.74E-06	4.29E-09	6.60E-06	3.26E-05	4.9
982	3'0.25" - 3'10"	0.22	4.84E-04	5.55E-07				6.66E-05	7.64E-08			
982	5'1.25" - 9'0.5"				1.46E-04	4.54E-04	3.1	3.82E-05	4.38E-08	6.52E-06	3.55E-05	5.4
982	5'1.5" - 5'11.75"	0.305	9.30E-04	1.07E-06				3.49E-05	4.00E-08			
982	6'0.25" - 6'3"	0.038	1.44E-05	1.66E-08				9.44E-06	1.08E-08			
982	6'3.5" - 8'	0.16	2.56E-04	2.94E-07				5.89E-05	6.76E-08			
982	8'0.5" - 9'	0.22	4.84E-04	5.55E-07				1.97E-06	2.26E-09			
982	10'1.5" -12'8.75"				6.10E-05	2.66E-05	0.4	5.52E-05	6.33E-08	3.33E-05	5.87E-05	1.8
982	10'1.5" - 11'1.5"	0.062	3.84E-05	4.41E-08				1.73E-05	1.98E-08			
982	11'2" - 12'8"	0.1	1.00E-04	1.15E-07				8.63E-05	9.90E-08			
982	15'0.5" - 19'7.5"				3.06E-04	3.47E-04	1.1	1.58E-04	1.81E-07	1.28E-04	1.36E-04	1.1
982	15'0.75" - 15'7.5"	0.2	4.00E-04	4.59E-07				1.89E-04	2.17E-07			
982	15'8" - 16'3.5"	0.2	4.00E-04	4.59E-07				1.72E-04	1.97E-07			
982	16'4" - 16'11.5"	0.18	3.24E-04	3.72E-07				1.59E-04	1.82E-07			
982	17'0.25" - 17'7.5"	0.12	1.44E-04	1.65E-07				9.12E-05	1.05E-07			
982	17'8" - 18'3.5"	0.205	4.20E-04	4.82E-07				1.30E-04	1.49E-07			
982	18'4" -18'11.5"	0.18	3.24E-04	3.72E-07				1.03E-04	1.18E-07			
982	19'0.25" - 19'7.5"	0.205	4.20E-04	4.82E-07				1.13E-04	1.30E-07			
983	1'5" - 4'4"				2.96E-04	1.33E-04	0.5	9.43E-05	1.08E-07			
983	1'7" - 3'	0.205	4.20E-04	4.82E-07								
983	3' -4'4"	0.15	2.25E-04	2.58E-07								
984	1'0.5" - 5"				3.85E-04	2.71E-04	0.7	1.59E-04	1.82E-07			
984	1' - 3'4"	0.28	7.84E-04	8.99E-07								
984	3'5" - 5'1"	0.15	2.25E-04	2.58E-07								
984	5'0.5"-9'4.75"							2.01E-05	2.31E-08			
984	5'1" - 5'11"				4.55E-04	2.08E-04	0.5	2.66E-06	3.05E-09			
984	6' - 8'	0.22	4.84E-04	5.55E-07								
984	8' - 9'5"	0.205	4.20E-04	4.82E-07								
984	10' - 15'				3.27E-05	3.43E-05	1.1	8.26E-06	9.47E-09			
984	10'1" - 10'11.5"	0.12	1.44E-04	1.65E-07				5.45E-06	6.25E-09			
984	11' - 14'3"	0.052	2.70E-05	3.10E-08								
984	15'1.25" - 17'2.5"							1.55E-06	1.78E-09	2.46E-06	4.04E-05	16.4
984	15'-16'							8.03E-05	9.21E-08			
984	16'0.75" - 17'2.5"	0.15	2.25E-04	2.58E-07				1.26E-06	1.45E-09			
984	20' - 24'				5.62E-05	3.87E-04	6.9	8.85E-07	1.02E-09			
984	20' - 21'4"	0.046	2.12E-05	2.43E-08								
984	21'4.5" - 22'2.5"	0.28	7.84E-04	8.99E-07				4.03E-07	4.62E-10			
984	22'3" - 23'11.5"	0.22	4.84E-04	5.55E-07								
011	0'8" -1'	0.2	4.00E-04	4.59E-07								
011	1'7" - 1'10.5"	0.12	1.44E-04	1.65E-07								
011	2'9" - 2'10"	0.16	2.56E-04	2.94E-07								
012	1'1.5" - 1'9"	0.19	3.61E-04	4.14E-07								
012	3'2" - 3'4"	0.22	4.84E-04	5.55E-07								
012	3'6"	0.2	4.00E-04	4.59E-07								
013	20'3.5" - 22'2.25"				5.44E-05	1.06E-04	2.0	3.11E-05	3.57E-08			
013	20'3" - 21'	0.15	2.25E-04	2.58E-07								

Well Number	Core Depth	Values from particle-size measurements						Values from permeameter measurements				
		Grain size d10 (mm)	Hazen's Hydraulic Conductivity C*d10 (C=100) (m/sec)	Intrinsic Permeability ki (cm2)	Equivalent Vertical Hydraulic Conductivity Kh (m/sec)	Equivalent Horizontal Hydraulic Conductivity Kz (m/sec)	Anisotropy Ratio Kh/Kz	Hydraulic Conductivity K (m/sec)	Intrinsic Permeability ki (cm2)	Equivalent Vertical Hydraulic Conductivity Kh (m/sec)	Equivalent Horizontal Hydraulic Conductivity Kz (m/sec)	Anisotropy Ratio Kh/Kz
013	21' - 21'6.5"	0.055	3.03E-05	3.47E-08								
013	21'6.5" - 22'2.5"	0.07	4.90E-05	5.62E-08								
013	30' - 35'											
013	31'3" - 31'9.5"	0.065	4.23E-05	4.85E-08								
013	31'7.5" - 31'10.8"	0.06	3.60E-05	4.13E-08								
013	31'10.8" - 32'	0.075	5.63E-05	6.45E-08								
013	32'8" - 33'3.5"	0.2	4.00E-04	4.59E-07								
019	1'7" - 4'2.5"				7.27E-05	1.78E-04	2.4	2.65E-07	3.04E-10	1.28E-07	5.24E-06	40.9
019	1'7" - 2'3"	0.205	4.20E-04	4.82E-07				7.51E-06	8.61E-09			
019	2'3.25" - 3'2"	0.12	1.44E-04	1.65E-07				9.32E-06	1.07E-08			
019	3'2.5" - 4'2.5"	0.06	3.60E-05	4.13E-08				5.00E-08	5.73E-11			
019	5'0.75" - 8'4.75"				8.36E-05	3.76E-04	4.5	1.92E-06	2.20E-09	1.24E-06	8.57E-05	69.1
019	5'0.5" - 5'10.25"	0.28	7.84E-04	8.99E-07				1.40E-04	1.61E-07			
019	5'11" - 6'1"	0.053	2.81E-05	3.22E-08				4.53E-07	5.20E-10			
019	6'1.5" - 7'4"	0.21	4.41E-04	5.06E-07				6.06E-05	6.95E-08			
019	7'4.5" - 8'4.25"	0.06	3.60E-05	4.13E-08				4.70E-07	5.39E-10			
019	10'2.5"- 11'	0.13	1.69E-04	1.94E-07								
019	11' - 13'5.5"	0.13	1.69E-04	1.94E-07								
019	15'0.75" -18'6.5"				1.48E-04	6.69E-05	0.5	2.61E-04	2.99E-07	1.43E-04	1.43E-04	1.0
019	15'1" - 15'8.75"	0.13	1.69E-04	1.94E-07				1.49E-04	1.71E-07			
019	15'9.5" - 18'6.25"	0.12	1.44E-04	1.65E-07				1.42E-04	1.63E-07			
019	20'0.5" - 24'2"				1.44E-04	1.65E-04	1.1	1.45E-06	1.66E-09	2.03E-06	1.55E-04	76.3
019	20'0.5" - 21'8"	0.14	1.96E-04	2.25E-07				2.45E-04	2.81E-07			
019	21'8.5" - 23'6.5"	0.13	1.69E-04	1.94E-07				1.21E-04	1.39E-07			
019	23'7" - 24'2"	0.08	6.40E-05	7.34E-08				2.89E-07	3.31E-10			
019	27'9" - 29'5.5"				1.64E-04	1.77E-04	1.1	9.60E-08	1.10E-10			
019	25' - 26'2"	0.12	1.44E-04	1.65E-07								
019	26'2.5" - 28'4"	0.15	2.25E-04	2.58E-07								
019	28'4" - 29'6"	0.11	1.21E-04	1.39E-07								
020	1'0.75" - 5'0.0625"				4.29E-04	2.53E-04	0.6	1.13E-04	1.30E-07	5.99E-06	8.85E-06	1.5
020	1'1" - 2'3.5"	0.205	4.20E-04	4.82E-07				3.13E-06	3.59E-09			
020	2'4.5" - 3'4.5"	0.21	4.41E-04	5.06E-07				7.68E-06	8.81E-09			
020	3'5" - 5'							1.41E-05	1.62E-08			
020	5'1" - 8'10.5"				3.80E-04	4.03E-04	1.1	2.14E-05	2.45E-08	3.47E-06	2.39E-05	6.9
020	5'6.5" - 6'11.5"	0.22	4.84E-04	5.55E-07				5.16E-05	5.92E-08			
020	7'0.25" - 8'1.5"	0.2	4.00E-04	4.59E-07				1.43E-06	1.64E-09			
020	8'2.25" - 8'10.5"	0.16	2.56E-04	2.94E-07				6.25E-06	7.17E-09			
020	10'1" - 13'10"				1.16E-04	7.13E-05	0.6	8.24E-05	9.45E-08	3.61E-05	7.33E-05	2.0
020	10'2.25" - 10'7.75"	0.07	4.90E-05	5.62E-08				7.23E-06	8.29E-09			
020	10'8" - 13'10"	0.12	1.44E-04	1.65E-07				8.26E-05	9.47E-08			
020	15'1.5" - 18'3.5"				1.84E-04	2.15E-04	1.2	2.65E-04	3.04E-07			
020	15'1.5" - 15'11.5"	0.12	1.44E-04	1.65E-07								
020	16' - 17'	0.12	1.44E-04	1.65E-07								
020	17' - 18'2.5"	0.18	3.24E-04	3.72E-07								
020	20'0.75" - 23'9.5"				3.83E-04	3.87E-04	1.0	2.17E-04	2.49E-07			
020	20' - 21'7.5"	0.2	4.00E-04	4.59E-07								
020	21'7.5" - 22'10"	0.205	4.20E-04	4.82E-07								
020	22'10.5"- 23'9"	0.18	3.24E-04	3.72E-07								
020	25' - 29'2"				9.48E-05	1.07E-04	1.1	6.59E-06	7.56E-09			
020	25' - 26'2"	0.12	1.44E-04	1.65E-07								
020	26'2" - 27'8"	0.08	6.40E-05	7.34E-08								
020	27'8" - 29'2"	0.11	1.21E-04	1.39E-07								
021	1'0.25" - 4'7.25"				3.43E-04	2.33E-04	0.7	1.63E-04	1.87E-07			
021	1' - 2'	0.14	1.96E-04	2.25E-07								
021	2' - 4'7"	0.22	4.84E-04	5.55E-07								
021	6'2" - 8'9.5"				2.43E-04	5.97E-04	2.5	8.01E-05	9.19E-08	1.75E-05	1.36E-05	0.8
021	6'2" - 6'11.75"	0.25	6.25E-04	7.17E-07				2.11E-05	2.42E-08			
021	7'0.5" - 7'11.5"	0.3	9.00E-04	1.03E-06				1.35E-05	1.55E-08			
021	8' - 8'8.95"	0.09	8.10E-05	9.29E-08				3.22E-06	3.69E-09			
021	11'6.25" - 14'							2.74E-05	3.14E-08			
021	10' - 14'				6.73E-04	7.57E-04	1.1					
021	10'1" - 11'6"	0.3	9.00E-04	1.03E-06								
021	11'6" - 13'5"	0.28	7.84E-04	8.99E-07								
021	13'5" - 14'	0.18	3.24E-04	3.72E-07				1.33E-06	1.53E-09			
021	15' -16'8"	0.19	3.61E-04	4.14E-07								
021	20'1.5" - 24'2"				8.60E-04	9.17E-04	1.1	2.46E-04	2.82E-07			
021	20' - 21'	0.28	7.84E-04	8.99E-07								
021	21' - 22'	0.37	1.37E-03	1.57E-06								
021	22' - 23'	0.28	7.84E-04	8.99E-07								
021	23' - 24'	0.27	7.29E-04	8.36E-07								
Minimum		0.04	1.44E-05	1.66E-08	1.69E-06	1.69E-06	0.44	5.00E-08	5.73E-11	1.28E-07	5.05E-06	0.77
Maximum		0.37	1.37E-03	1.57E-06	8.60E-04	9.17E-04	6.89	2.75E-04	3.15E-07	1.43E-04	1.55E-04	76.28
Mean		0.16	2.24E-04	2.57E-07			1.40	2.02E-05	2.31E-08			15.40
Median		0.18	3.24E-04	3.72E-07			1.07	3.49E-05	4.00E-08			2.03

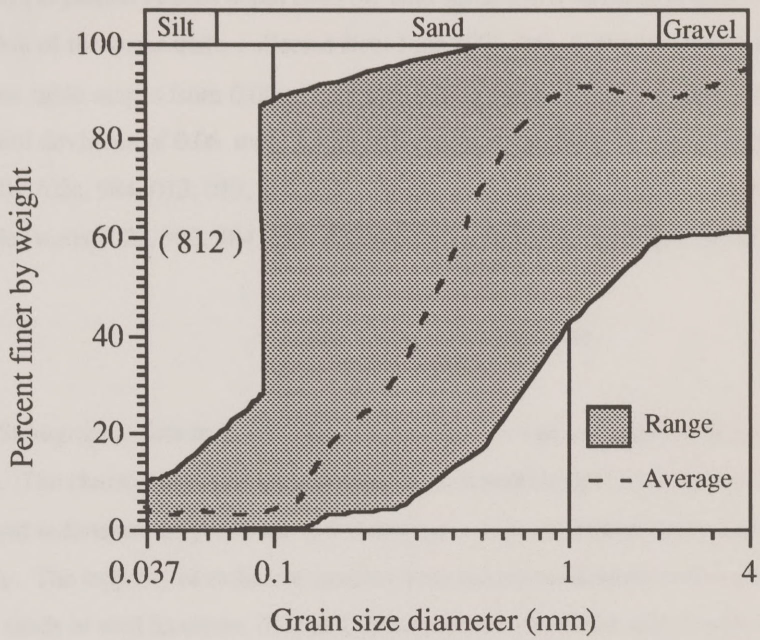


Figure III.5 Range and average of grain size distribution curves of 812 data points from 102 core samples taken from Bemidji. MN research site sediments.

distribution curve indicates an average d_{10} of 0.13 mm and d_{50} of 0.31 mm. (d_{50} is the location where 50 percent of the grain sizes are finer.) The curve is slightly bimodal with modes of 0.13 and 1 mm.

d_{10} is plotted against depth from the land surface in a series of graphs in Figure III.6. The location of the water table, collected from June 1990 data, is displayed on each plot. The d_{10} at the water table ranges from 0.08 to 0.28 mm with a mean of 0.17 mm, median of 0.16 mm, and standard deviation of 0.06 mm. Large differences in d_{10} occur in the vicinity of the water table (wells 702c, 984, 012, 019, and 021). An increase in d_{10} is present immediately below the water table (wells 702c, 982, 984, 013, 020, and 021), however, d_{10} decreases at depth.

Visual Core Descriptions

Stratigraphic data from this study (Appendix A2) was compared with previously collected well logs. The characteristics of three distinctive sedimentological units, gravel layers, silt layers, and wetland sediments, are presented in this thesis and were determined from core data from this study only. The majority of sediment samples were mostly moderately sorted medium sands. Gravelly sands in well locations 702c and 019 correlate to a similar unit at well location 702a. This unit varies in thickness from 1-1.5 m and is located with the top coinciding with the location of the water table. Northeast of the wetland area, sediments in well locations 982 and 020 correlate with sediments in surrounding well locations 417d, 418c, 419c, and 001. All well logs have a thick unit, up to 16 m thick, of predominantly medium to coarse sand with a few finer-grained layers located sporadically throughout the outwash.

Gravel Units

Stratigraphic interpretations indicate the presence of a thick granule and pebble gravel unit that underlies most of the site at depths below land surface of 1-10 m (Figure III.8; Figure III.9). The unit varies in thickness from 1 to more than 3 m and extends laterally more than 440 m. Table III.3 lists in detail the location of the gravel unit.

In addition to the large gravel layer at depth, several smaller discontinuous gravel units are located throughout the sediments. A discontinuous unit of medium to very coarse sand with granules and pebbles is located at well locations 702c, 019, and 020 (Figure III.7; Figure III.9).

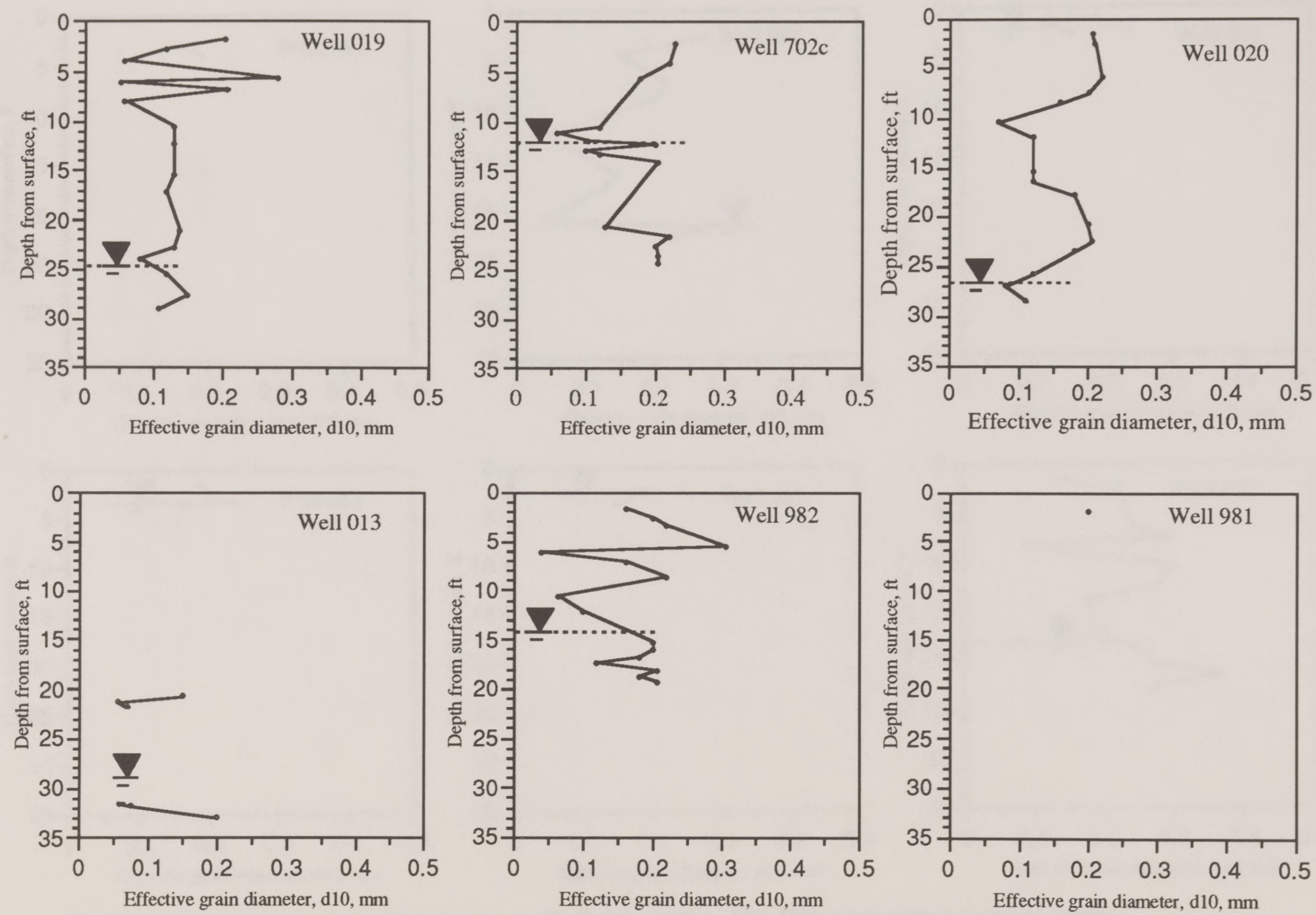


Figure III.6 (a) Effective grain diameter versus depth of core samples. June 1990 water table is shown on graphs.

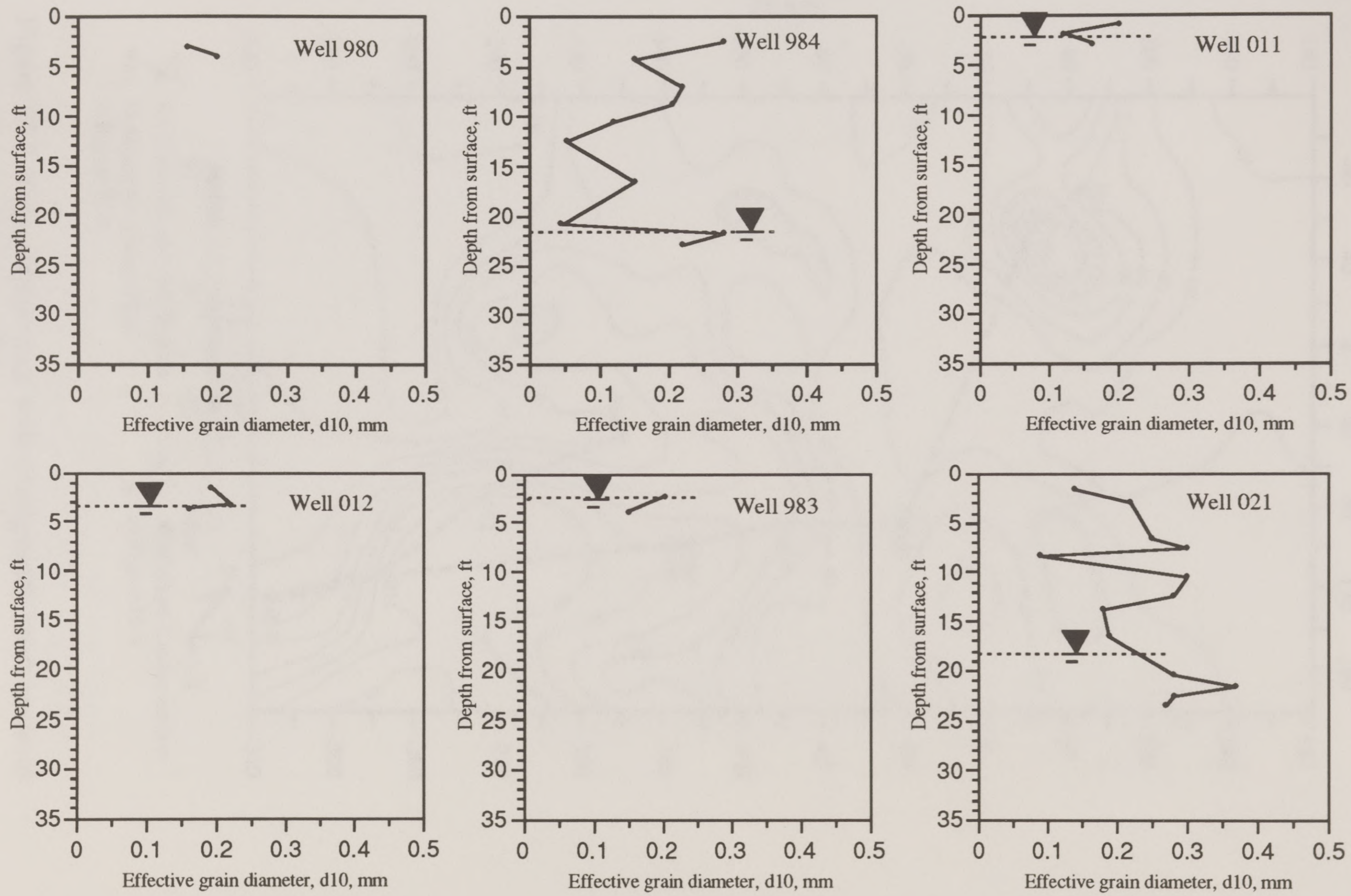


Figure III.6 (b) Effective grain diameter versus depth of core samples. June 1990 water table is shown on graphs.

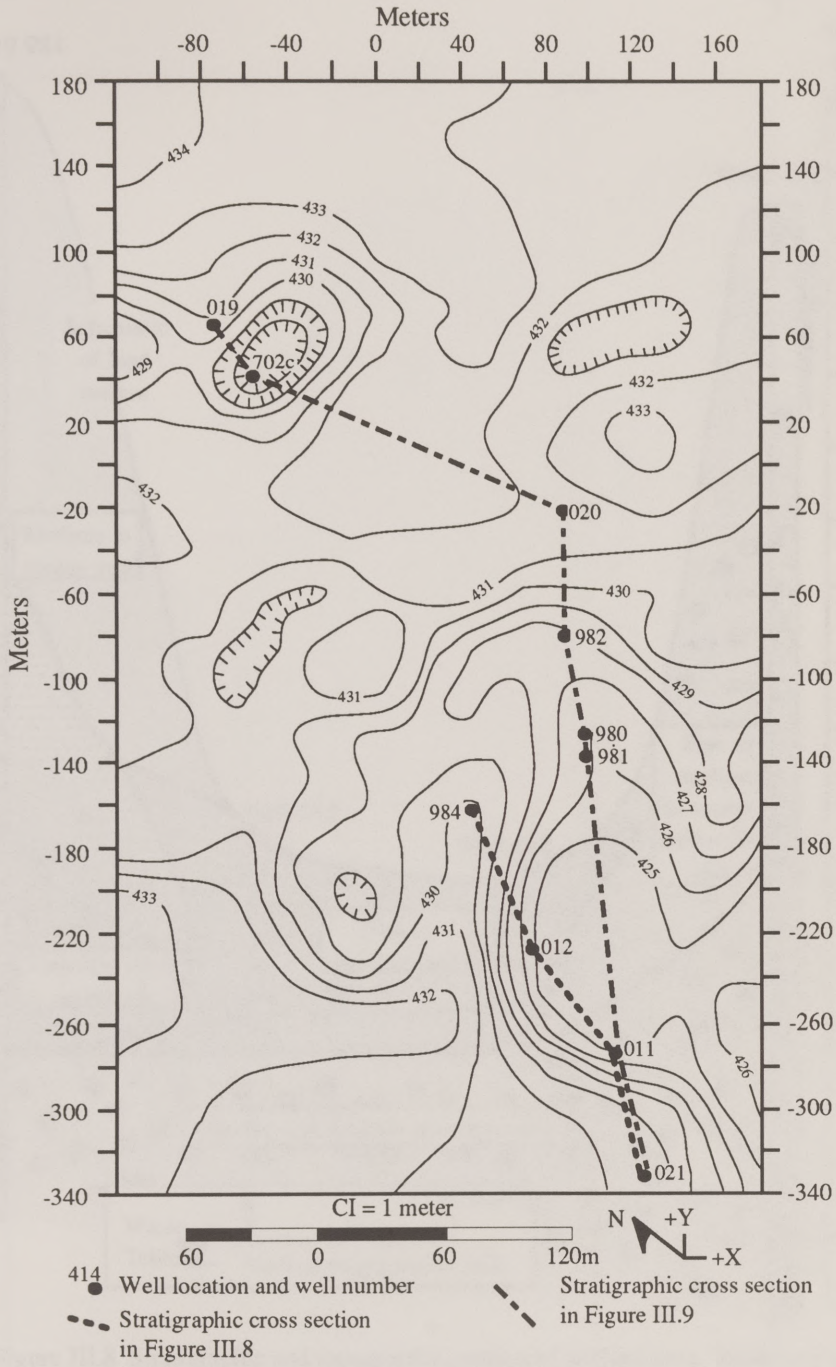


Figure III.7 Topographic map with stratigraphic cross sections seen in Figures III.8 and III.9.

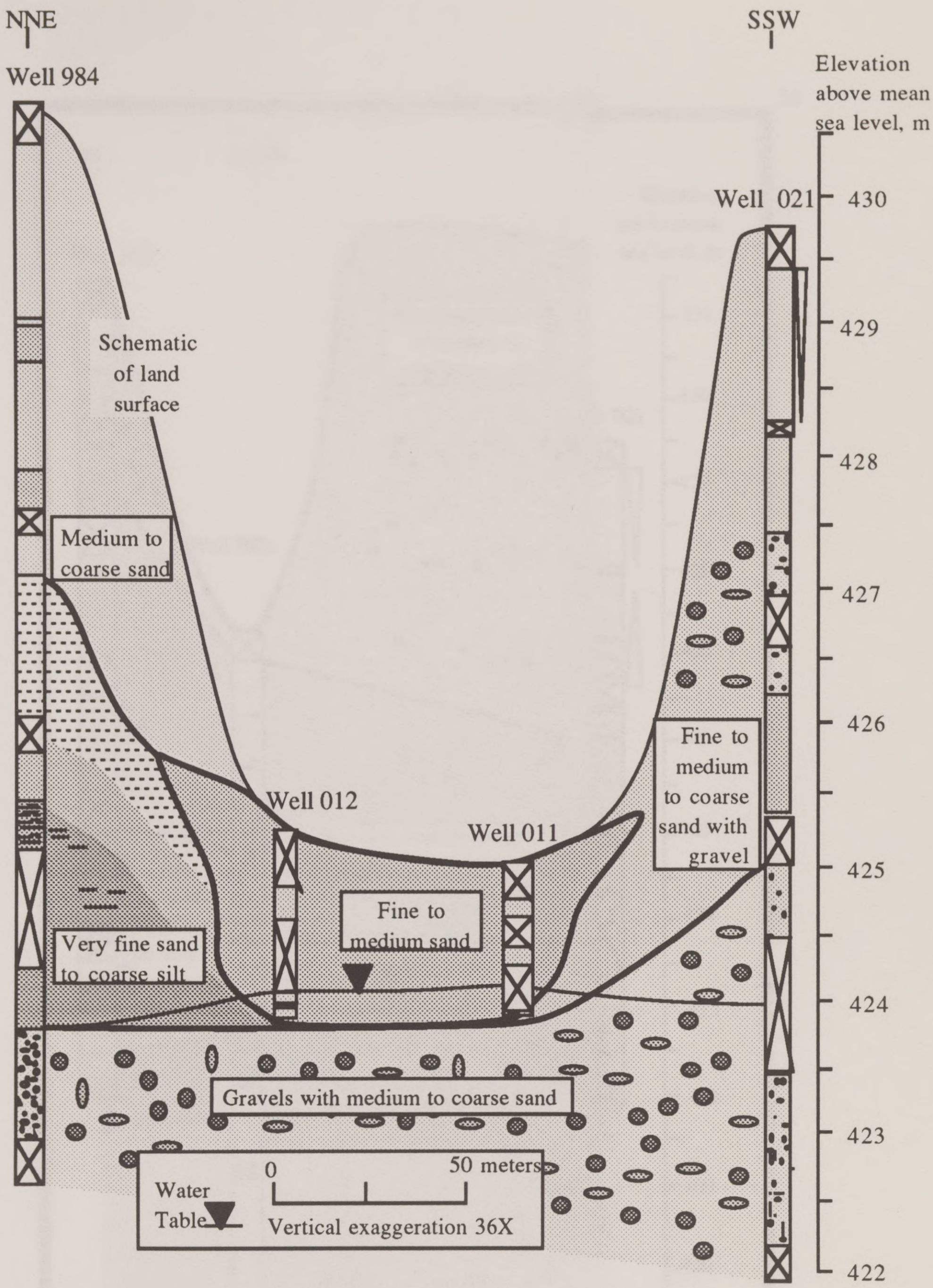


Figure III.8 Stratigraphic and topographic profiles of wetland area. Refer to Figure III.7 for location of cross section and Appendix A2 for explanation of sediment symbols. Stratigraphic interpreations made from sediment textural analysis and visual core descriptions

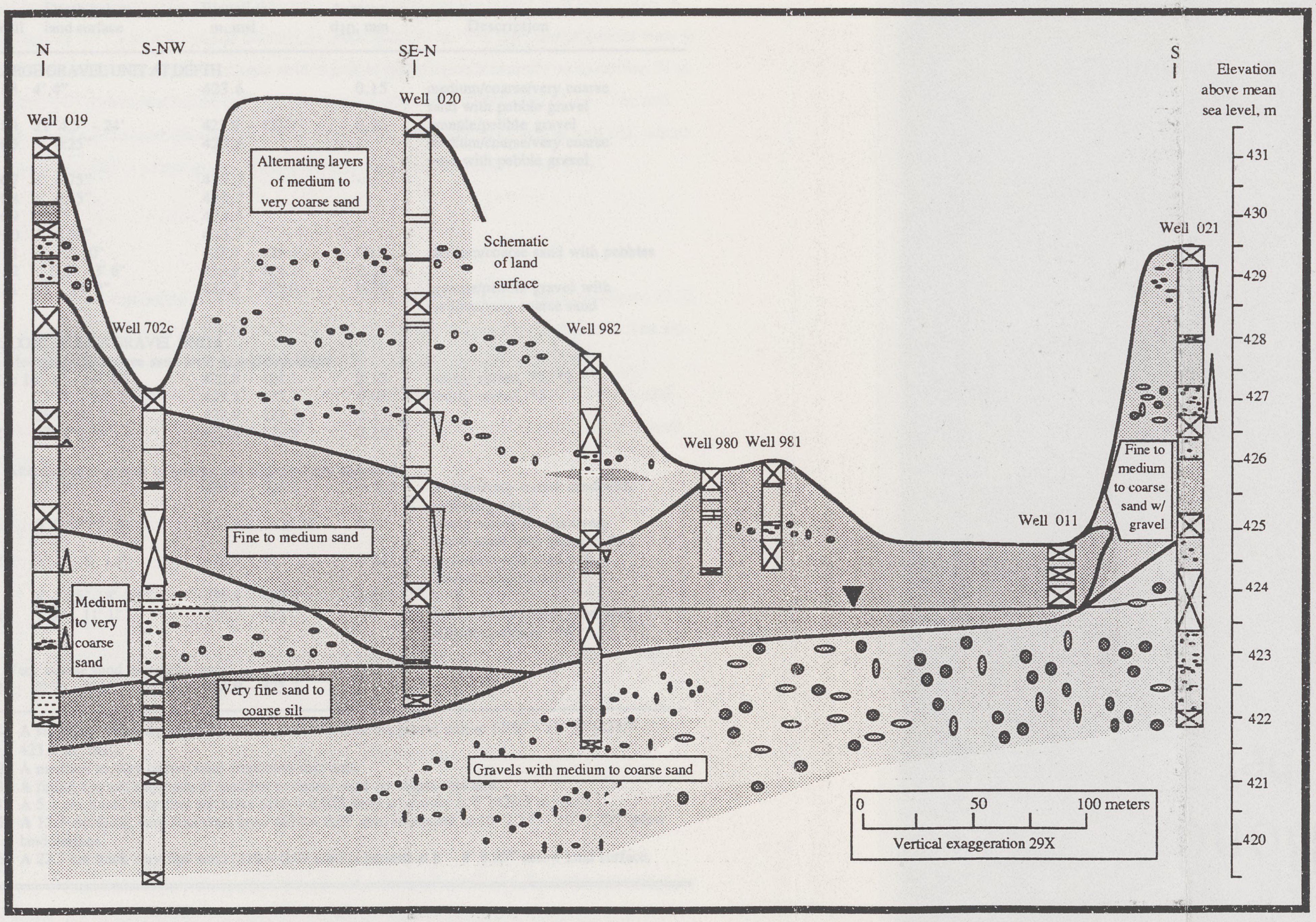


Figure III.9 Stratigraphic and topographic profiles across site. Refer to Figure III.7 for location of cross section and Appendix A2 for explanation of sediment symbols. Stratigraphic interpretation made from sediment textural analysis and visual core descriptions

Table III.3 Gravel Units

Well	Depth below land surface	Elevation m, msl	Average d_{10}, mm	Description
LARGE GRAVEL UNIT AT DEPTH				
983	4' 4"	423.6	0.15	medium/coarse/very coarse sand with pebble gravel
984	21' 4.5" - 24'	422.9 - 423.7	0.25	granule/pebble gravel
003	3' 0.25"	423.6	-	medium/coarse/very coarse sand with pebble gravel
007	3' 6.75"	423.7	-	"
008	4' 9.75"	423.7	-	"
009	3' 2"	423.5	-	"
010	2' 6.25"	423.7	-	"
011	8" - 2' 10"	423.7 - 424.4	0.18	medium/coarse sand with pebbles
012	1' 0.5" - 3' 6"	423.9 - 424.7	0.21	"
021	15' - 24' 2"	422.2 - 425.0	0.28	granule/pebble gravel with medium/very coarse sand
DISCONTINUOUS GRAVEL UNITS				
A. Medium/very coarse sand with granules/pebbles				
702c	10' 1" - 14' 4.5"	422.8 - 424.1	0.12	poorly sorted, *1, *2
019	23' 7" - 24' 2"	423.5 - 423.7	0.08	poorly sorted, *3
	25' - 26' 2"	422.9 - 423.3	0.12	"
020	27' 8" - 28'	422.8 - 422.9	0.10	-
B. Alternating sequence of coarse and slightly finer sediments				
982	5' - 6'	425.9 - 426.3	0.305	medium/very coarse sand with pebbles/gravels
019	5' 0.5" - 7' 4"	428.65 - 429.35	0.25	poorly sorted medium/very coarse sand with granules,*4
020	1' 1" - 8' 1.5"	428.9 - 430	0.21	medium/coarse sand with fine/very coarse sand
	8' 2.25"-18' 2.5"	425.8 - 428.8	0.14	", *5
021	7' 9" - 11' 1"	426.2 - 427.2	0.3	medium/very coarse sand with granules/pebbles, *6
C. Very coarse sand to pebble gravel				
981	2' 7" - 3' 4"	424.9 - 425.2	-	-

*1 A silt layer with a d_{10} of 0.06 mm is present within the gravel unit at 10'9" - 11' 5" (423.7 - 423.8 m, msl).
*2 A medium to very coarse sand envelopes this unit.
*3 A fining upward sequence of medium to coarse sand envelopes this unit.
*4 A 5.1 cm thick, very fine silt layer (d_{10} = 0.053 mm) is present at 6' (426.3 m, msl).
*5 A 12.7 cm thick, very fine sand layer (d_{10} = 0.07 mm) is present at 10' 2.25" - 10' 7.75" below land surface.
*6 A 22.7 cm thick very fine sand (d_{10} = 0.09 mm) is present at 8' - 8' 8.95" below land surface.

It ranges in thickness from 0.1-1.3 m and extends laterally more than 30 m. A second discontinuous gravel body is found at wells 982, 019, 020, and 021 (Figure III.8; Figure III.9). This unit is characterized by an alternating sequence of coarse and less coarse sediments, varies in thickness of 0.3 - 3 m, and extends laterally no more than 240 m. The third discontinuous body is located at well 981, where a very coarse sand to pebble gravel extends laterally no more than 50 m (Figure III.9).sequence of coarse and less coarse sediments, varies in thickness of 0.3 - 3 m, and extends laterally no more than 240 m. The third discontinuous body is located at well 981, where a very coarse sand to pebble gravel extends laterally no more than 50 m (Figure III.9).

Silt Units

A thick, continuous silt layer is found at well locations 702c, 019, and 020 (Figure III.9). The water table and the large gravel unit, previously discussed, directly overlie this unit. The silt layer varies in thickness from 0.4 to 0.7 m and extends laterally no more than 180 m.

Smaller, thinner discontinuous silt layers are scattered throughout the site laterally and vertically (wells 702c, 982, and 019 in Figure III.9). Table III.4 lists the silt units found at well locations.

Wetland Area

The wetland area consists mostly of fine to medium sands (wells 011 and 012 in Figures III.8 and III.9, and well 983 in Appendix A2). Tree material was found near the land surface in well 980. Near the water table, grain size increases to very coarse sandy gravel with some pebbles and boulders.

Groundwater Monitoring

Water Table Maps

Water table maps were generated from water levels taken throughout 1989-1991 (Figures III.10-III.17). Water level data of water table wells is displayed in Appendix A3. Locations of water table wells used for generating each map are indicated for each time period. Equipotential

Table III.4 Silt Units

Well	Depth below land surface	Elevation m, msl	Average d_{10}, mm	Description
LARGE SILT UNIT NEAR THE WATER TABLE				
702c	15' - 17' 4"	421.9 - 422.6	0.12	coarse silt with medium sand near bottom
019	28' 4" - 29' 6"	421.6 - 422.3	0.11	silt to very fine sand
020	27' 8" - 29' 2"	422.4 - 422.9	0.11	very fine/fine sand
SMALL DISCONTINUOUS SILT UNITS				
702c	10' 9" - 11' 3"	423.8-423.9	0.06	medium/coarse silt
982	6' 0.25" - 6' 3"	425.9-425	0.038	coarse silt with very fine sand
	10' 1.5" - 11' 1.5"		0.062	-
984	11' - 14' 3"	425.9-426.9	0.052	coarse silt
	16' 0.75" - 21' 4"	423.7-425.4	0.09	coarse silt/very fine sand
019	3' 2.5" - 3' 3.5"	429.89-429.91	0.06	coarse silt/very fine sand
	7' 4.5" - 8' 4.25"	428.3-428.6	0.06	coarse silt/fine sand
	29' 5.5"	421.9	*1	clay/very fine silt with angular granules (till)
	5' 11" - 6' 1"	420.04 - 429.1	0.053	-

*1 Upon completion of core retrieval for this hole, the auger was found to be coated in a greenish-gray clay to very fine silt with angular coarse granules. No sample was taken for grain-size analysis, however, field observations indicated that this material was the most fine gained sediment found at the site. It is described as a till.

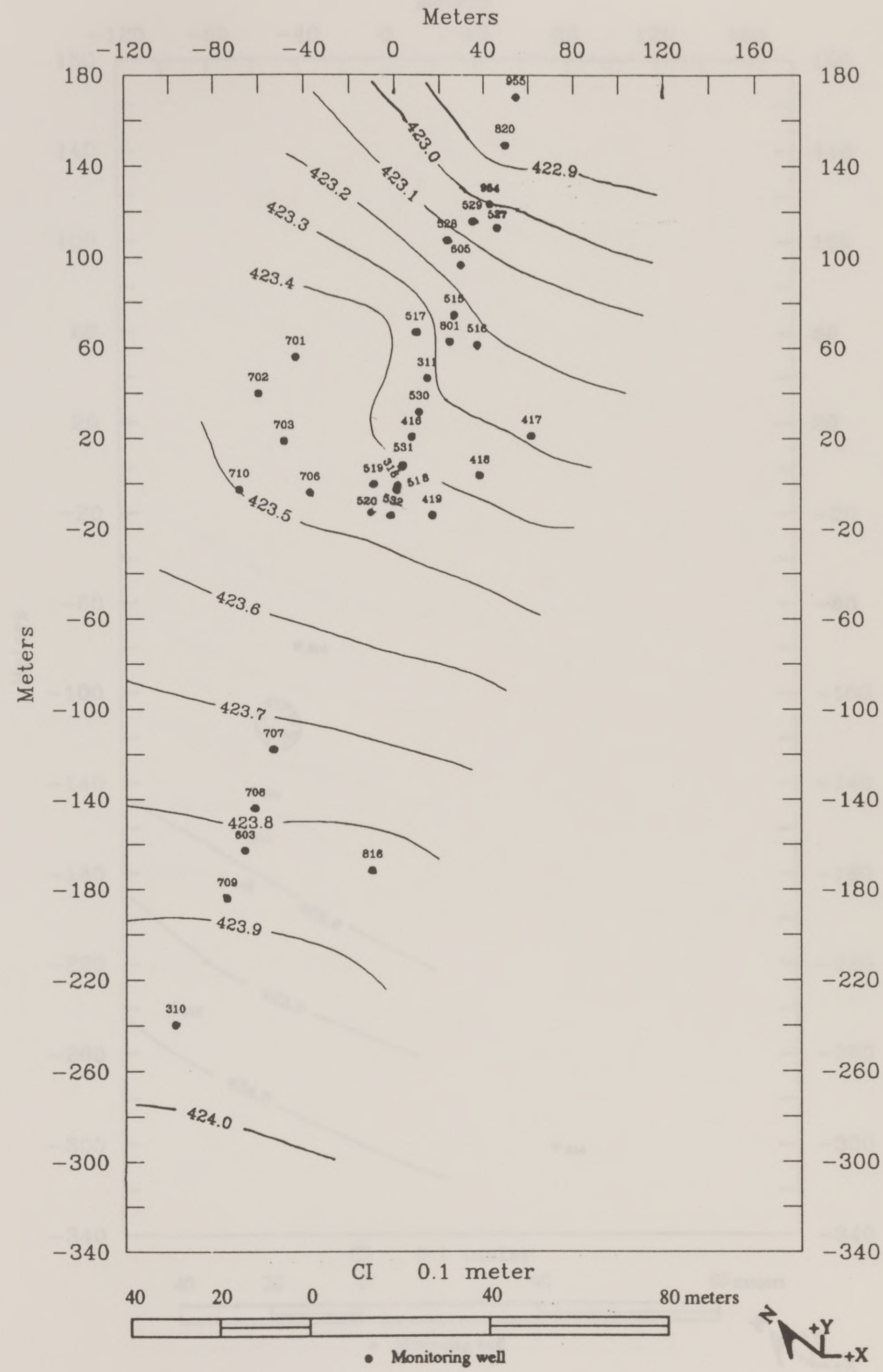


Figure III.10 August 1989 Water table map

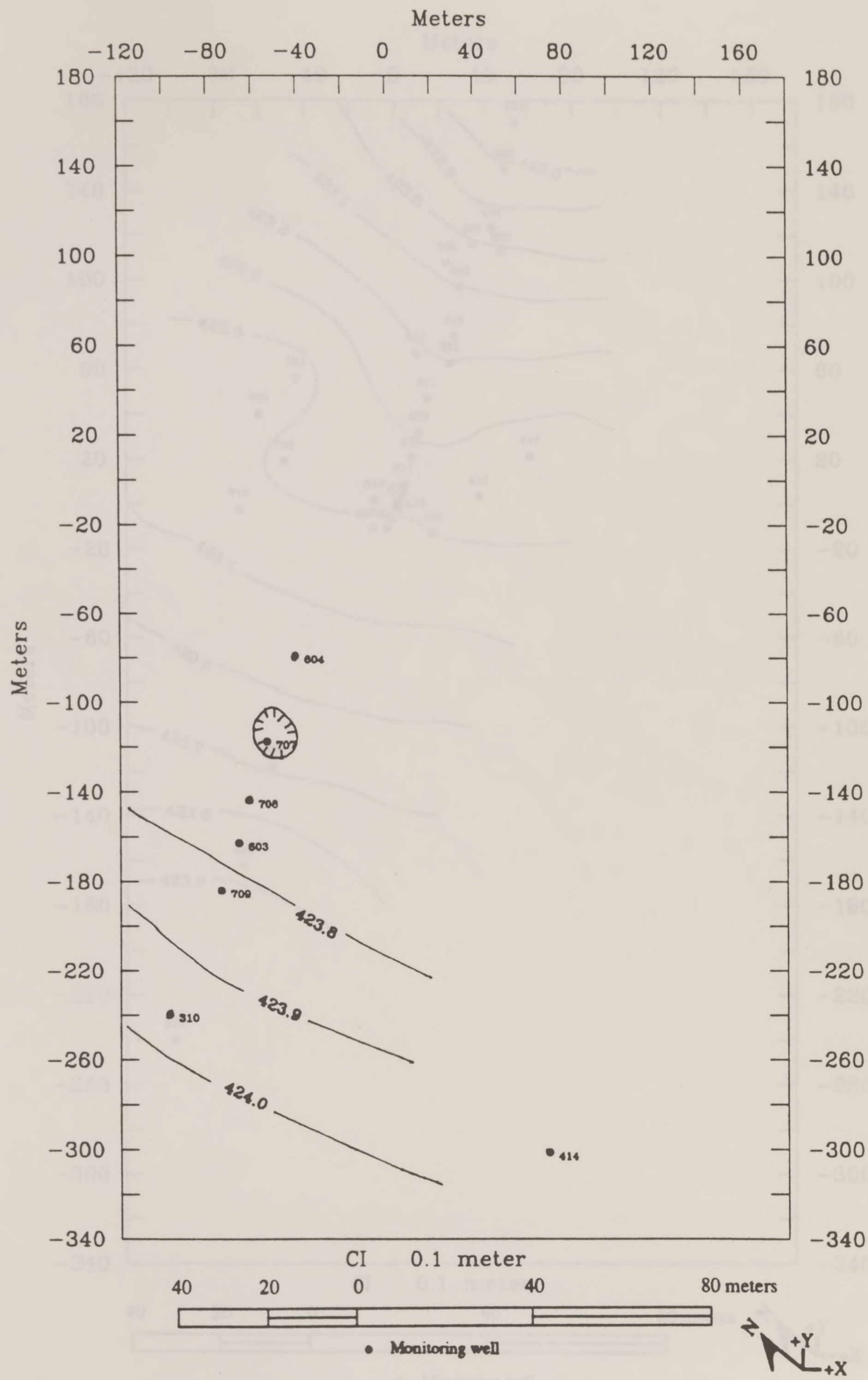


Figure III.11 September 8, 1989 Water table map

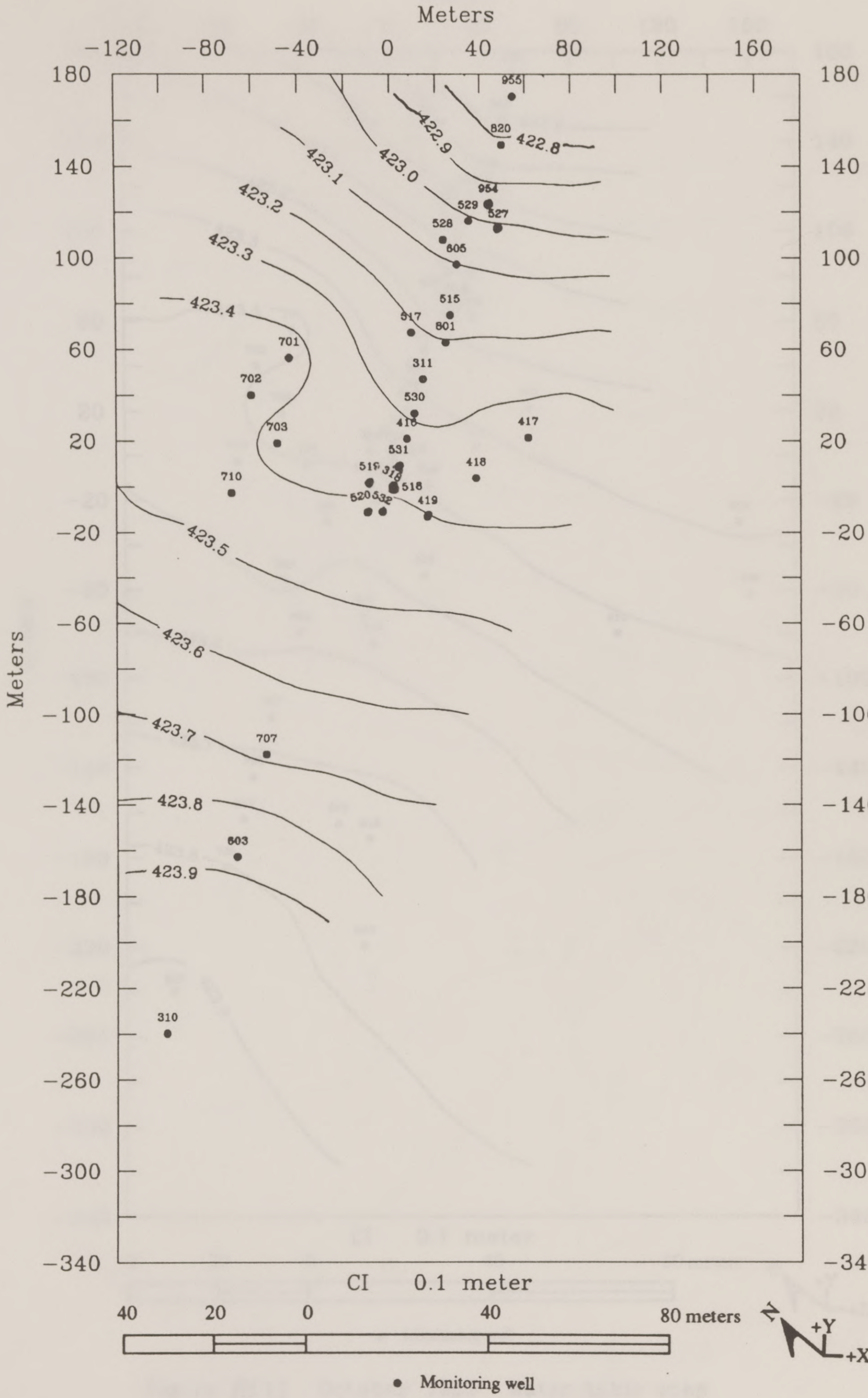


Figure III.12 September 23, 1989 Water table map

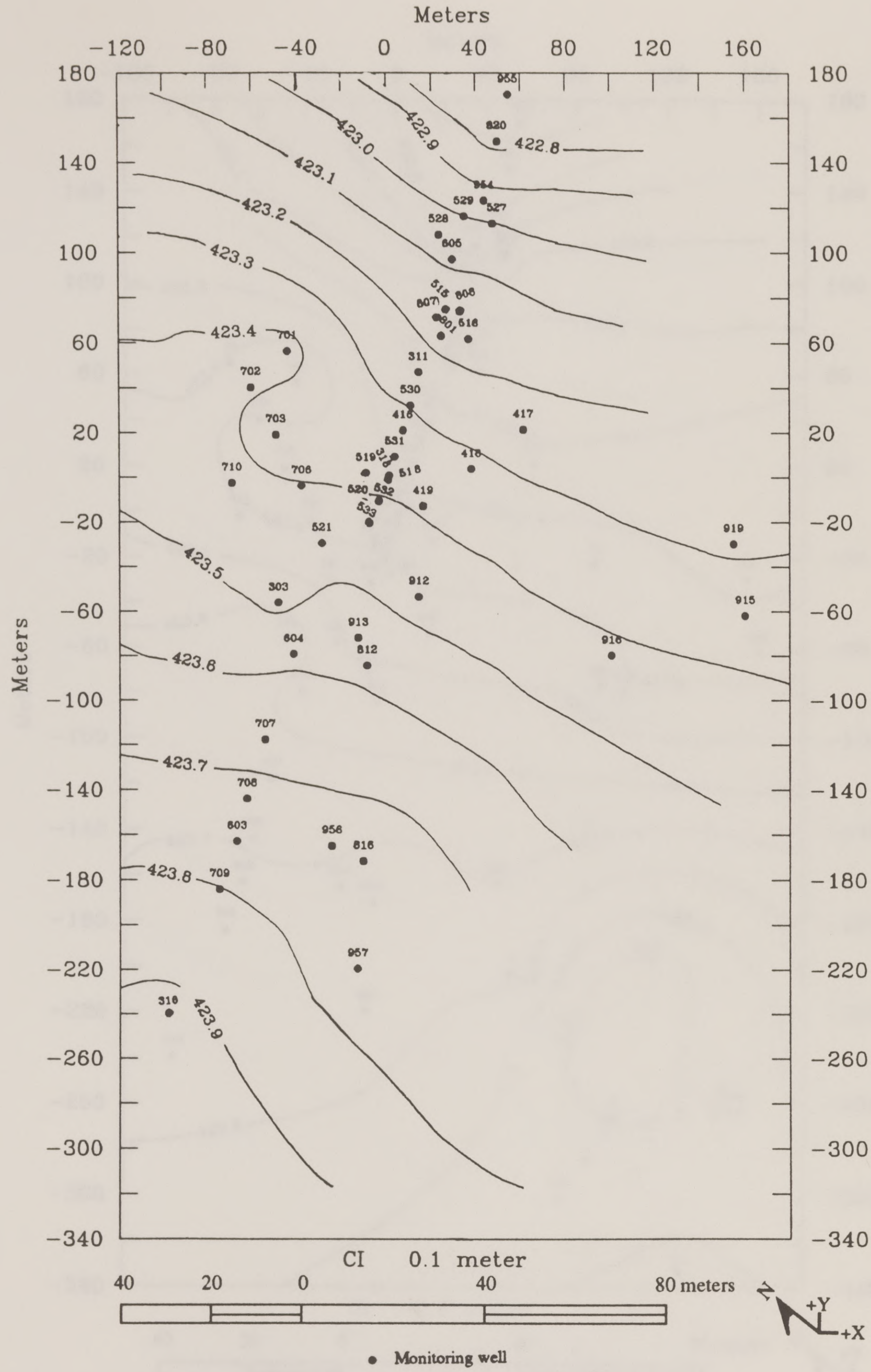


Figure III.13 October 1989 Water table map

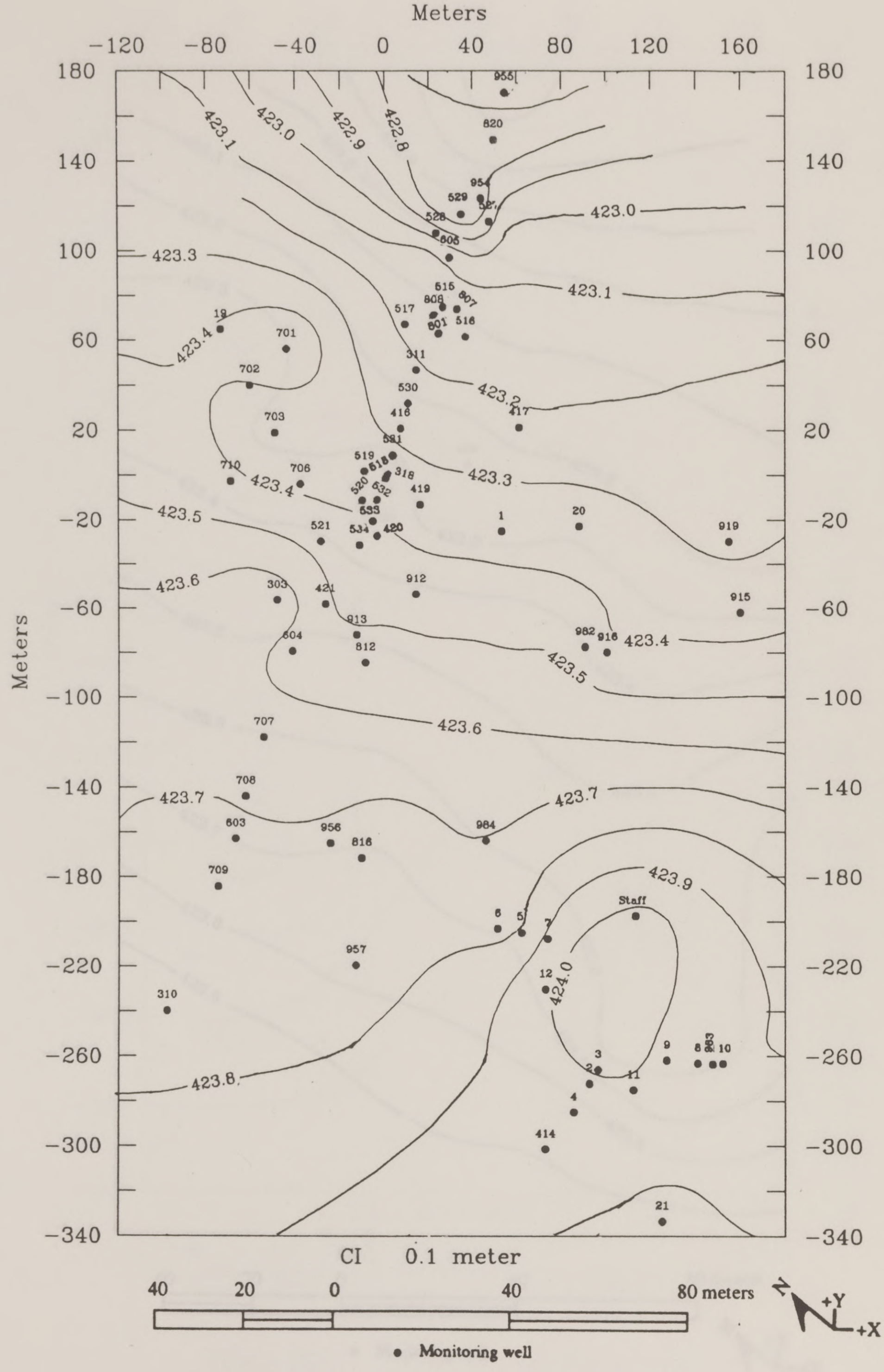


Figure III.14 June 1990 Water table map

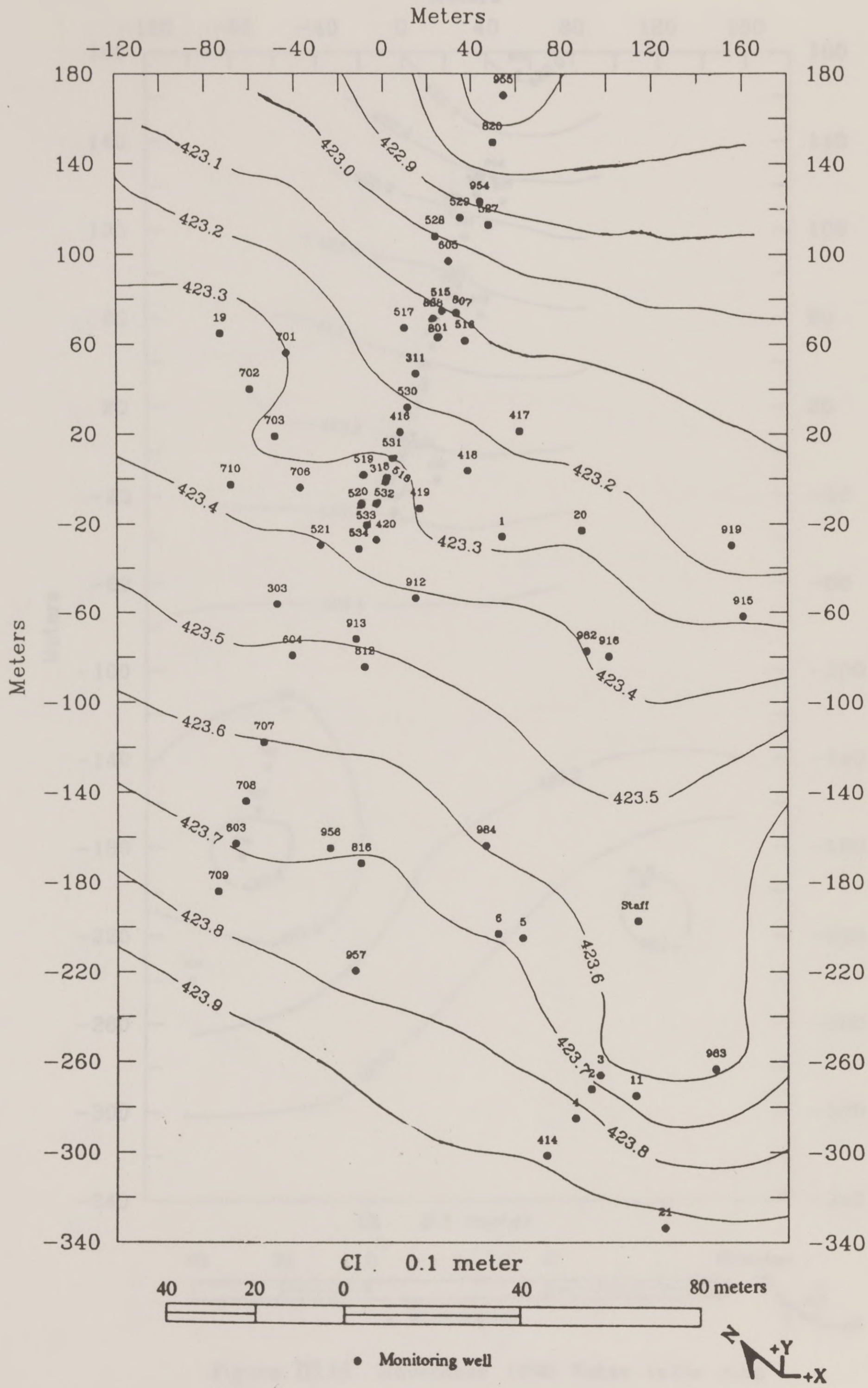


Figure III.15 August 1990 Water table map

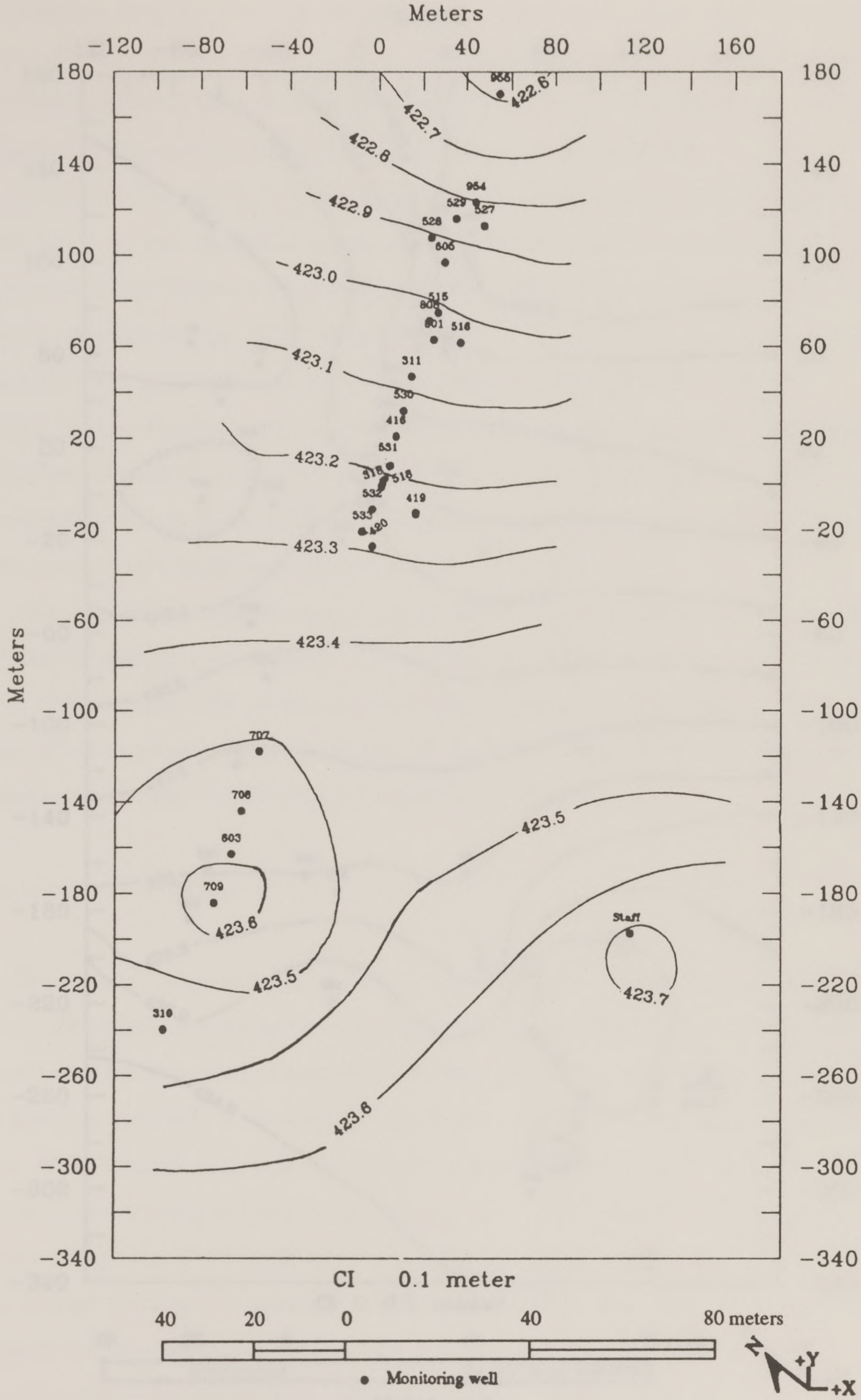


Figure III.16 November 1990 Water table map

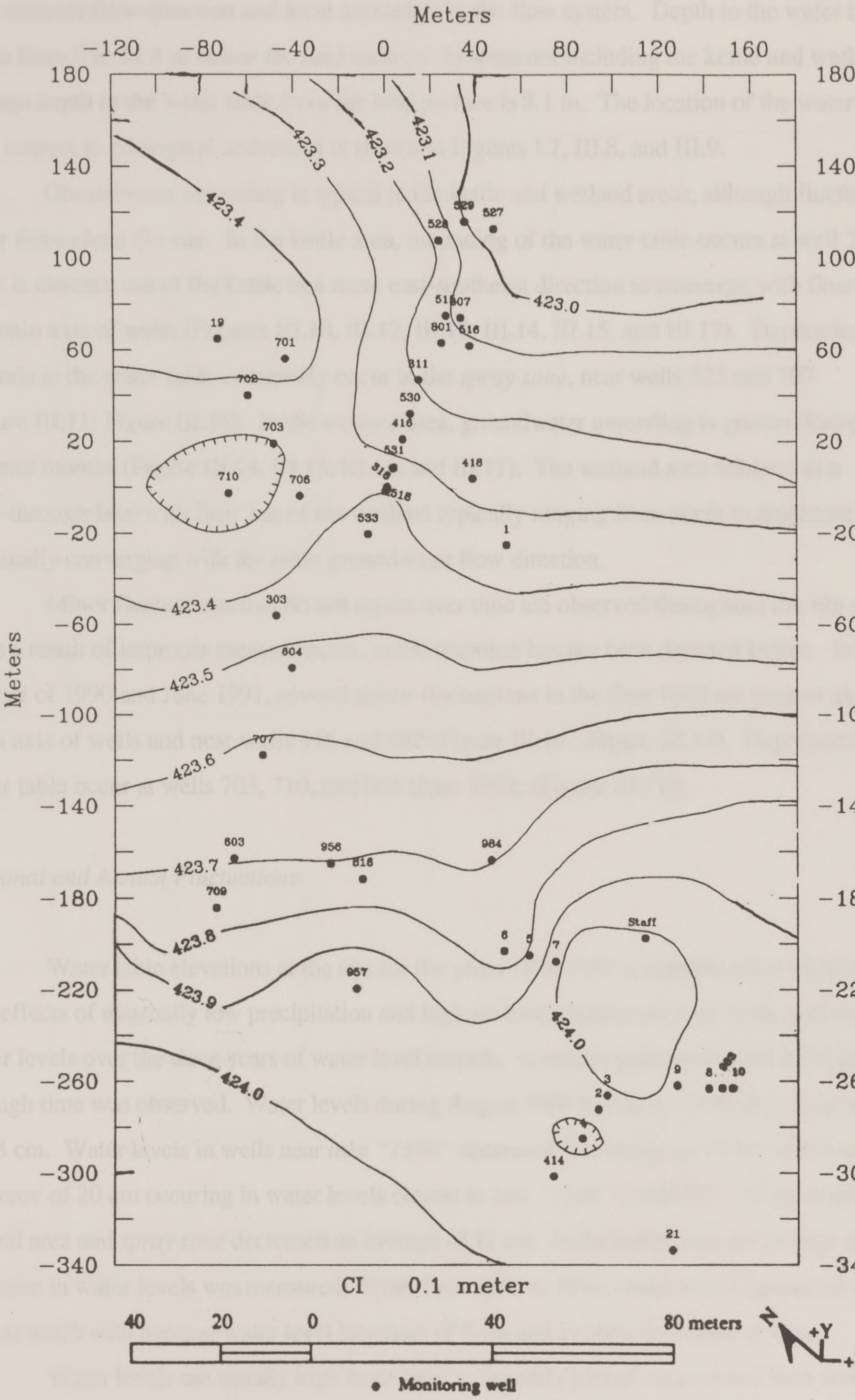


Figure III.17 June 1991 Water table map

lines indicate flow direction and local anomalies in the flow system. Depth to the water table varies from 0 to 11.4 m below the land surface. In areas not including the kettle and wetland, the average depth to the water table from the land surface is 8.1 m. The location of the water table with respect to geological sediments is shown in Figures I.7, III.8, and III.9.

Groundwater mounding is typical in the kettle and wetland areas, although fluctuations occur throughout the site. In the kettle area, mounding of the water table occurs at well 701a. Flow is directed out of the kettle in a more east-southeast direction to converge with flow along the main axis of wells (Figures III.10, III.12, III.13, III.14, III.15, and III.17). Depressions or mounds in the water table commonly occur in the *spray zone*, near wells 523 and 707 (Figure III.11; Figure III.16). In the wetland area, groundwater mounding is greater during the summer months (Figure III.14, III.15, III.16, and III.17). The wetland area behaves as a flow-through lake with flow out of the wetland typically ranging from north to southeast, eventually converging with the main groundwater flow direction.

Minor fluctuations that do not repeat over time are observed throughout the site and may be as a result of improper measurements, as the response has not been detected before. In June and August of 1990 and June 1991, several minor fluctuations in the flow field are present along the main axis of wells and near wells 916 and 982 (Figure III.14 ; Figure III.17). Depressions in the water table occur at wells 703, 710, and 004 (June 1991; (Figure III.17)).

Seasonal and Annual Fluctuations

Water table elevations at the site for the years 1989-1991 are displayed in Figure III.18. The effects of unusually low precipitation and high air temperatures are seen in the decrease in water levels over the three years of water level records. A similar pattern of water level changes through time was observed. Water levels during August 1989 to August 1990 decreased an average of 13 cm. Water levels in wells near *lake "1386"* decreased an average of 14 cm with a maximum decrease of 20 cm occuring in water levels closest to *lake "1386"* (well 925). Water levels in the central area and *spray zone* decreased an average of 11 cm. In the kettle area, an average of 15 cm decrease in water levels was measured. From June 1990 to 1991, water levels fluctuated almost half as much with average water level increases of 8 cm and average decreases of 4 cm.

Water levels are usually high from June to the early part of autumn and then drop off steadily throughout the rest of the year (August to September 1989 in Figures III.10 and III.11;

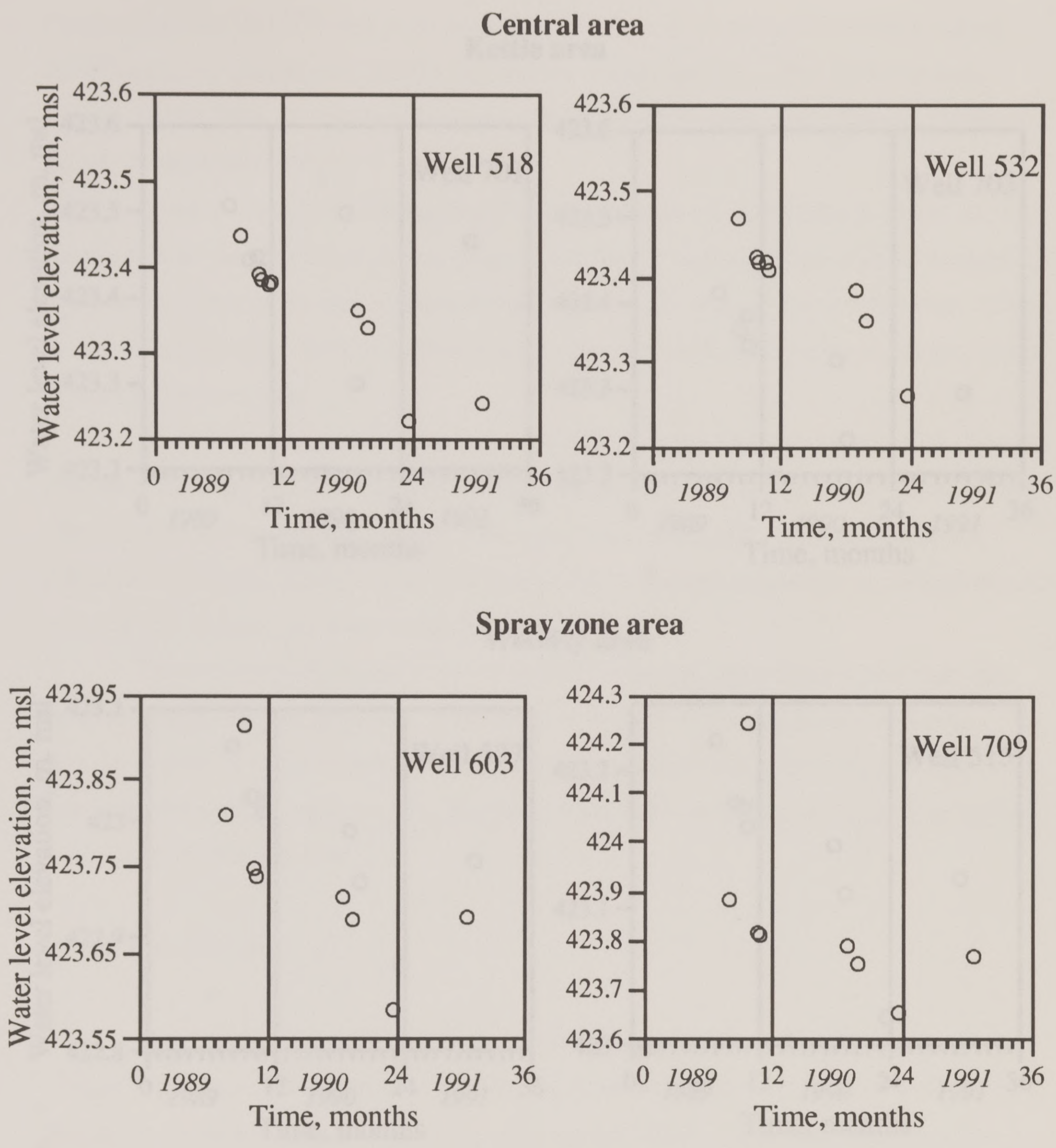


Figure III.18 (a) Water level measurements of water table wells in the central and *spray zone* areas.

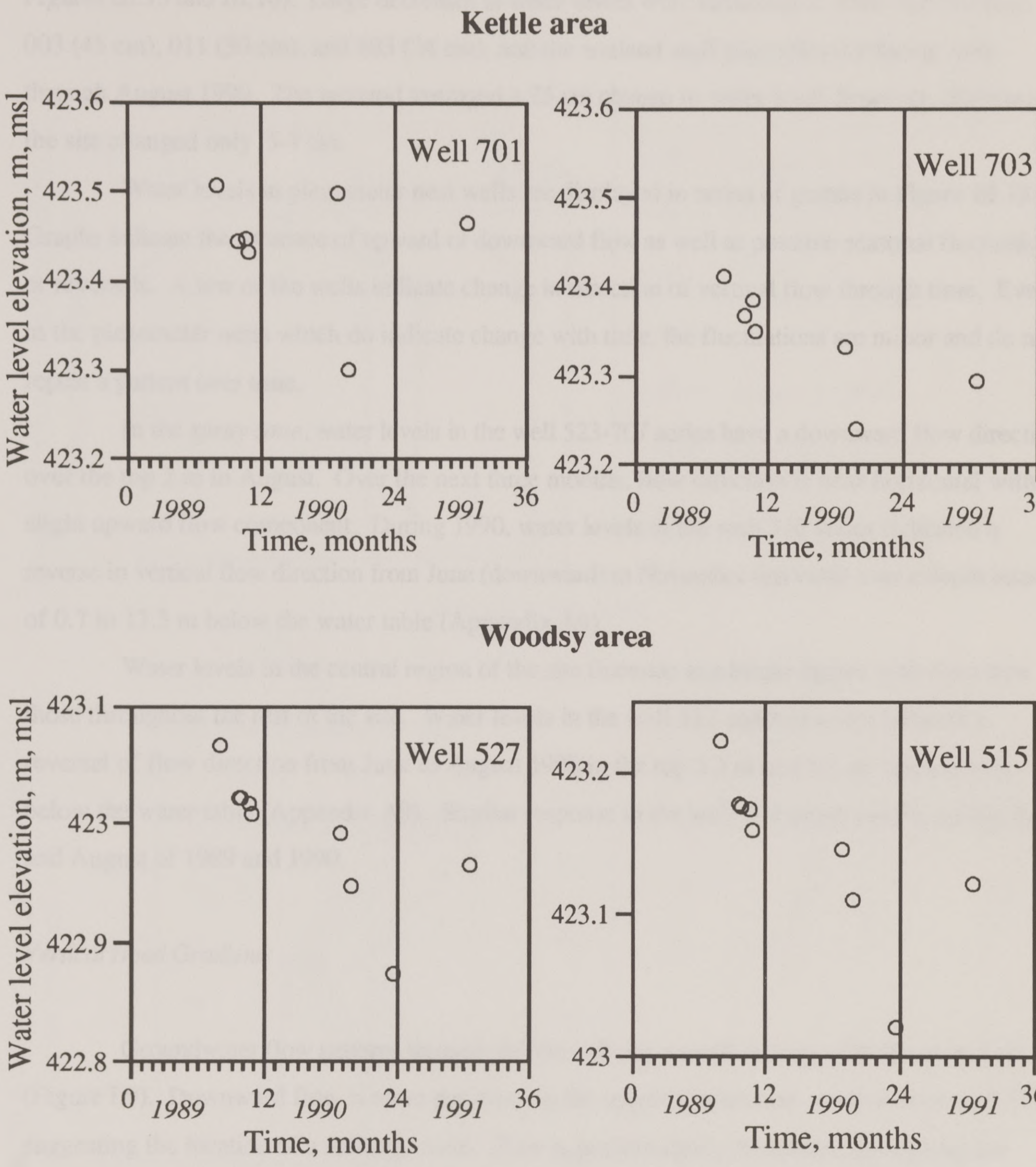


Figure III.18 (b) Water level measurements of water table wells in the woodsy northeastern section near *lake "1386"* and the kettle.

September to October 1989 in Figures III.12 and III.13; August to November 1990 in Figures III.15 and III.16). Large decreases in water levels were measured in wells 925 (12 cm), 003 (45 cm), 011 (30 cm), and 983 (34 cm), and the wetland staff gage (50 cm) during June through August 1990. The wetland averaged a 25 cm change in water level, however, the rest of the site changed only 5-7 cm.

Water levels in piezometer nest wells are displayed in series of graphs in Figure III.19. Graphs indicate the presence of upward or downward flow as well as possible seasonal fluctuations or reversals. A few of the wells indicate change in direction of vertical flow through time. Even in the piezometer nests which do indicate change with time, the fluctuations are minor and do not repeat a pattern over time.

In the *spray zone*, water levels in the well 523-707 series have a downward flow direction over the top 2 m in August. Over the next three months, flow direction is near horizontal with a slight upward flow component. During 1990, water levels in the well 310 series indicated a reverse in vertical flow direction from June (downward) to November (upward) over a depth interval of 0.7 to 17.3 m below the water table (Appendix A9).

Water levels in the central region of the site fluctuate to a larger degree with time than those throughout the rest of the site. Water levels in the well 417 and 418 series indicate a reversal of flow direction from June to August 1990 in the top 5.2 m and 8.4 m, respectively, below the water table (Appendix A9). Similar response in the well 532 series is seen during June and August of 1989 and 1990.

Vertical Head Gradients

Groundwater flow patterns through the site indicate a small recharge-discharge system (Figure I.9). Downward flow is more prevalent in the upgradient section, southwest of well 530, suggesting the location of a recharge zone. Flow is predominantly horizontal throughout the center of the site and becomes dominated by upward flow northeast of well 530 where the horizontal hydraulic gradient steepens before approaching *lake "1386"* (Figures III.10, III.12, III.13, III.14, III.15, III.16, and III.17). Water level data of piezometer nest wells are displayed in Appendix A9.

South of the wetland upward flow near the water table occurs with an average upward vertical gradient of 1:215 present in the top 4.5 m (wells 401, 503, and 504, Appendix A9) and

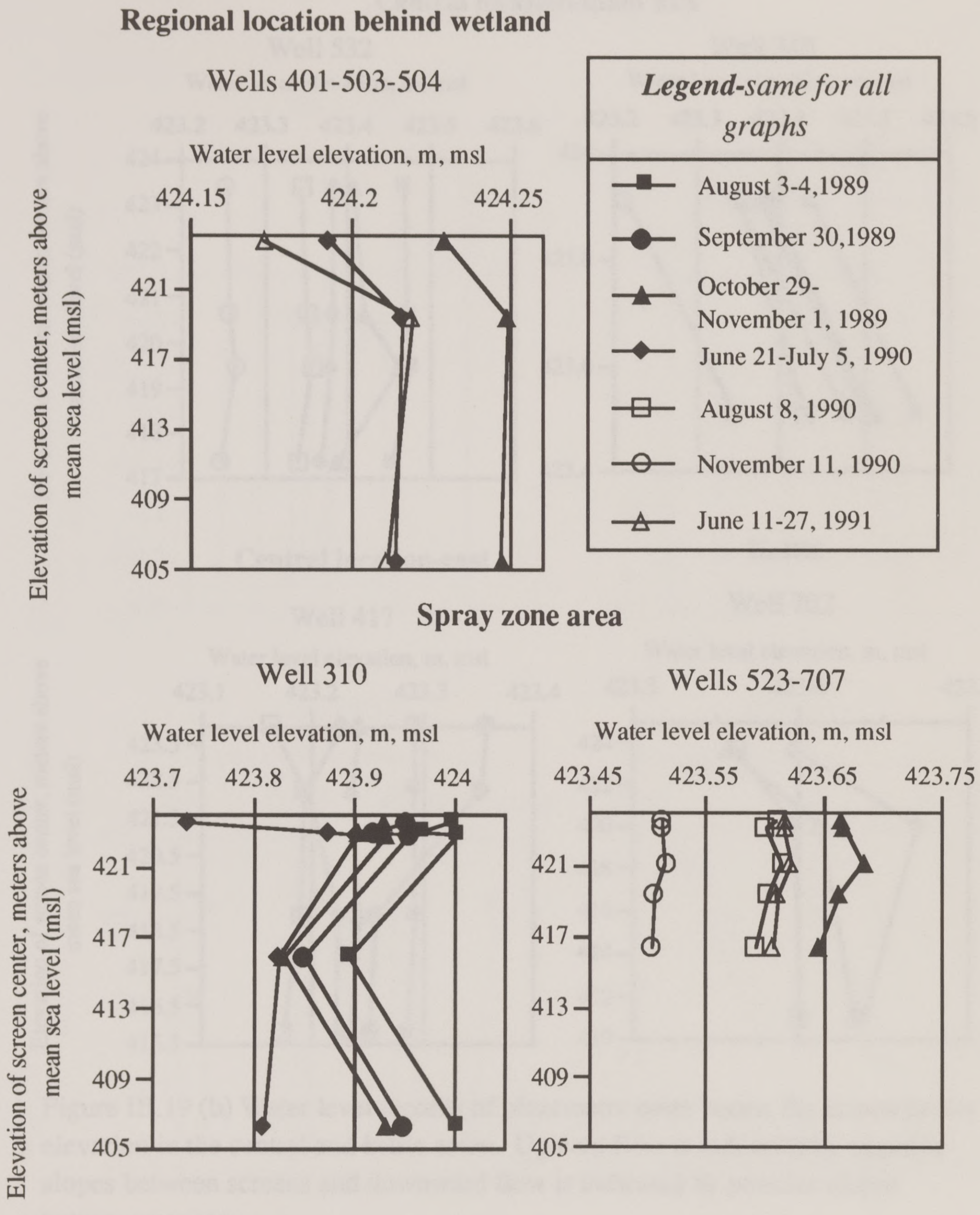


Figure III.19 (a) Water level records of piezometer nests versus the screen center elevation in the *spray zone* and regional areas. Upward flow is indicated by negative slopes between screens and downward flow is indicated by positive slopes between screens.

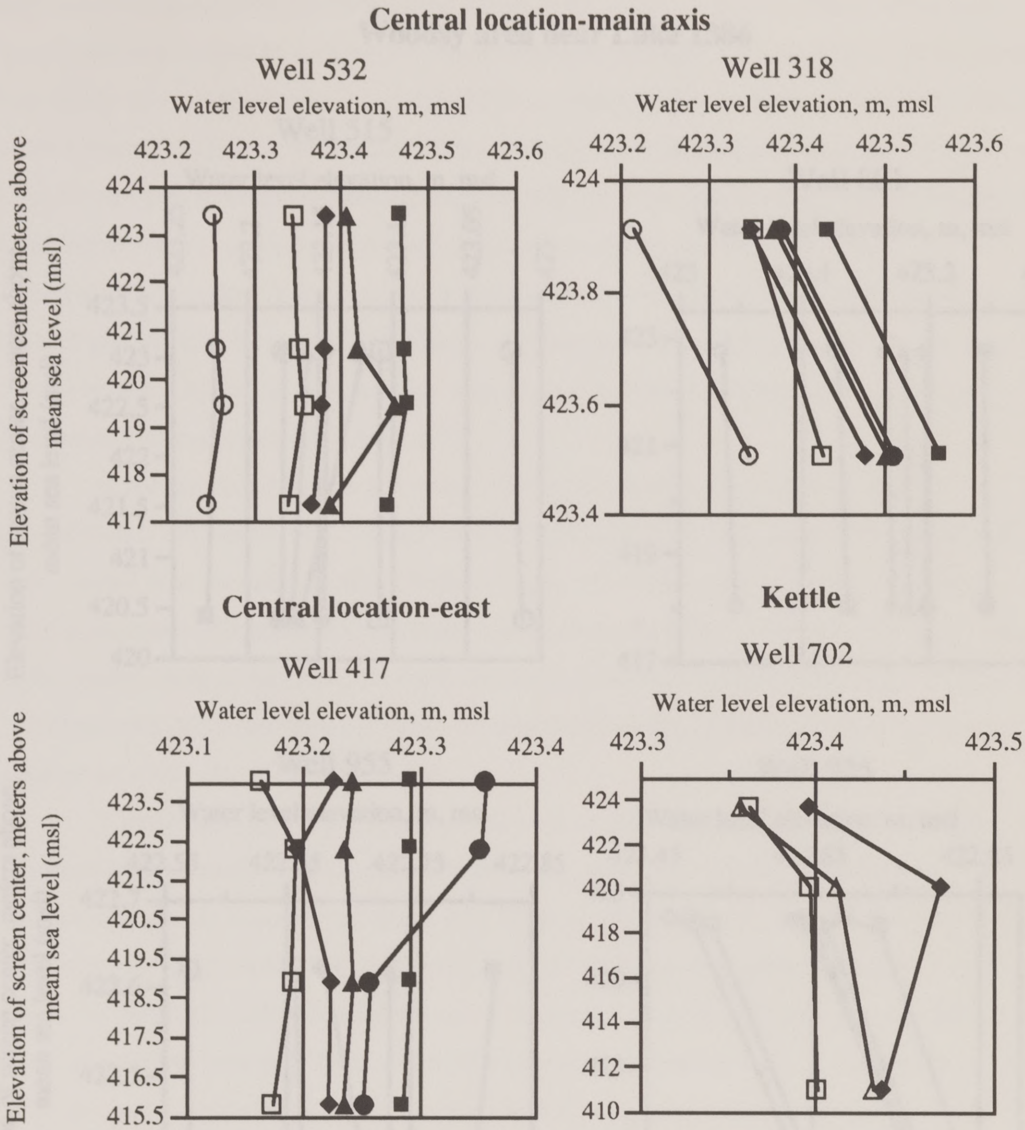


Figure III.19 (b) Water level records of piezometer nests versus the screen center elevation in the central and kettle areas. Upward flow is indicated by negative slopes between screens and downward flow is indicated by positive slopes between screens.

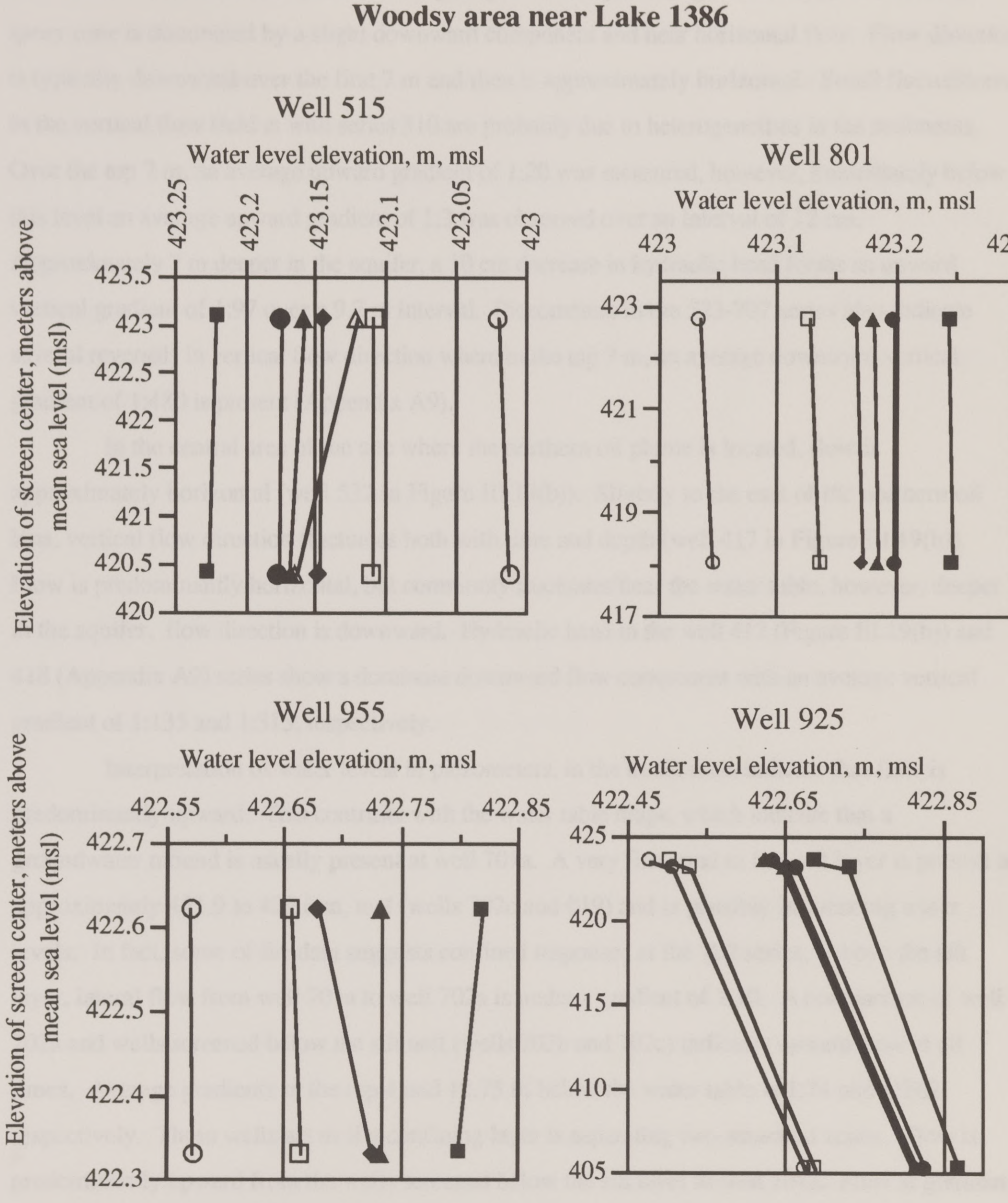


Figure III.19 (c) Water level records of piezometer nests versus the screen center elevation in the northeastern woodsy area near *lake "1386"*. Upward flow is indicated by negative slopes between screens and downward flow is indicated by positive slopes between screens.

near horizontal to downward flow occuring deeper in the aquifer (Figure III.19(a)). Flow in the *spray zone* is dominated by a slight downward component and near horizontal flow. Flow direction is typically downward over the first 7 m and then is approximately horizontal. Small fluctuations in the vertical flow field at well series 310 are probably due to heterogeneities in the sediments. Over the top 7 m, an average upward gradient of 1:20 was measured, however, immediately below this level an average upward gradient of 1:3 was observed over an interval of 12 cm. Approximately 7 m deeper in the aquifer, a 10 cm decrease in hydraulic head forms an upward vertical gradient of 1:97 over a 9.7 m interval. Piezometers in the 523-707 series also indicate several reversals in vertical flow direction where in the top 7 m, an average downward vertical gradient of 1:480 is present (Appendix A9).

In the central area of the site where the northern oil plume is located, flow is approximately horizontal (well 532 in Figure III.19(b)). Slightly to the east of the northern oil lens, vertical flow direction fluctuates both with time and depth (well 417 in Figure III.19(b)). Flow is predominantly horizontal, but commonly fluctuates near the water table, however, deeper in the aquifer, flow direction is downward. Hydraulic head in the well 417 (Figure III.19(b)) and 418 (Appendix A9) series show a dominant downward flow component with an average vertical gradient of 1:135 and 1:315, respectively.

Interpretation of water levels in piezometers, in the kettle area, indicate that flow is predominantly upward. This contrasts with the water table maps, which indicate that a groundwater mound is usually present at well 701a. A very fine sand to fine silt layer is present at approximately 421.9 to 422.6 m, msl (wells 702c and 019) and is possibly influencing water levels. In fact, some of the data suggests confined responses at the 702 series. Above the silt layer, lateral flow from well 701a to well 702a is under a gradient of 1:10. A comparison of well 702a and wells screened below the silt unit (wells 702b and 702c) indicates upward flow at all times. Average gradients in the top 4 and 12.75 m below the water table is 1:74 and 1:262, respectively. These wells act as if a confining layer is separating two saturated zones. Flow is predominantly upward from the wells screened below the silt layer to well 701a. Flow at gradients ranging from 1:45 to 1:5 is present at most times from wells above the silt layer (wells 701a and 702a) to the well in the silt layer (well 308).

Flow direction is mostly downward from wells screened above the silt layer in the kettle area (wells 701a and 702a) to well 308a, a well screened in the silt layer. The average downward gradient is 1:14. Upward flow from the wells screened below the silt layer to well 308a was present. Upward gradients increase with depth from 1:20 (measured over a depth of 2.2 m below the silt layer) to 1:90 (measured over a depth of 11.3 m below the silt layer). Flow is mostly horizontal with a slight upward component from well 702c (deeper in the aquifer) to well 702b, but a downward gradient was measured during June 1990.

The piezometer nests in the woodsy area, near lake "1386", indicate mostly upward flow (Figure III.19 (c)) The average vertical gradient is approximately 1:800. Piezometers in the well 925 series indicate upward flow along a depth of 18.5 m below the water table (Appendix A9). Near the water table the average vertical gradient is 1:15 (upward), but at depth it decreases to 1:115 (upward). Compared with a regional horizontal hydraulic gradient of 1:352, groundwater flow is predominantly vertical in this well.

Hydraulic Conductivity

For ease in viewing comparisons of hydraulic conductivities of core samples, Appendix A5 and Table III.2 should be used in conjunction with this section. Appendix A5 shows the cores and hydraulic conductivities obtained from measurements and calculations. Hydraulic conductivities and statistical data are listed in Table III.2.

Measured and Calculated Hydraulic Conductivity

Hydraulic conductivities measured from a permeameter range from 10^{-8} to 10^{-4} m/s with a mean of 2.02×10^{-5} m/s and median of 3.49×10^{-5} m/s (Table III.2). Intrinsic permeabilities ranged from 10^{-11} to 10^{-7} cm^2 with a mean of 2.31×10^{-8} cm^2 and a median of 4×10^{-8} cm^2 (Table III.2). The largest range of hydraulic conductivity within a 1.5 m core length was at well location 019, depth of 6.1-7.6 m, where 2.89×10^{-7} to 2.45×10^{-4} m/s was measured.

Measured hydraulic conductivities cover a large range of values representative of till to gravel type sediments (Figure III.20). The majority of measured hydraulic conductivities range from 10^{-6} to 10^{-4} m/s (Figure III.20), typically representative of sand size sediment.

Calculated hydraulic conductivities range from 10^{-5} to 10^{-3} m/s with a mean of 2.24×10^{-4} m/s and a median of 3.24×10^{-4} m/s (Table III.2). Intrinsic permeabilities range from 10^{-8} to 10^{-6} cm^2 with a mean of 2.57×10^{-7} cm^2 and a median of 3.72×10^{-7} cm^2 (Table III.2). The largest range in hydraulic conductivity within a well location was calculated at well location

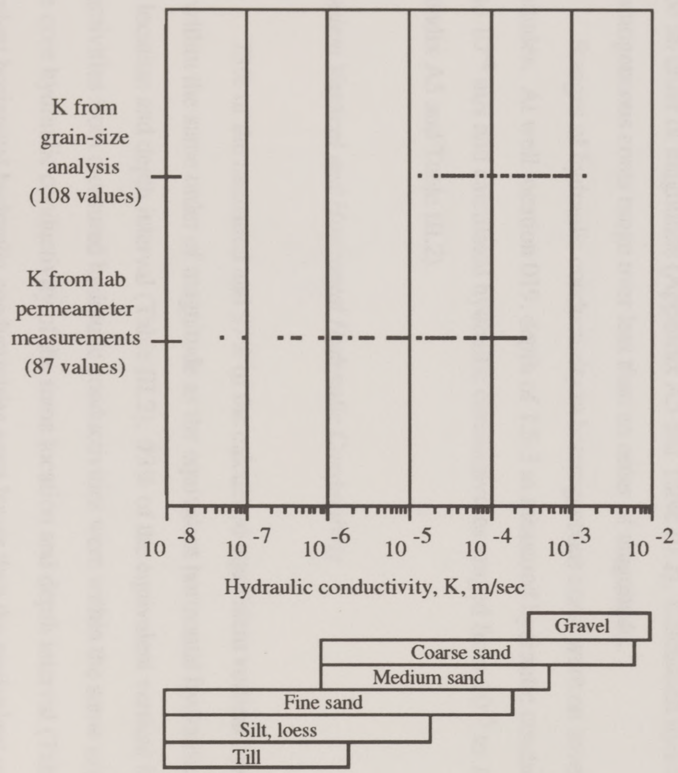


Figure III.20(a) Resulting values of hydraulic conductivities from lab permeameter measurements and grain-size analysis. Values of K for typical sediments listed below graph are from Domenico and Schwartz (1990).

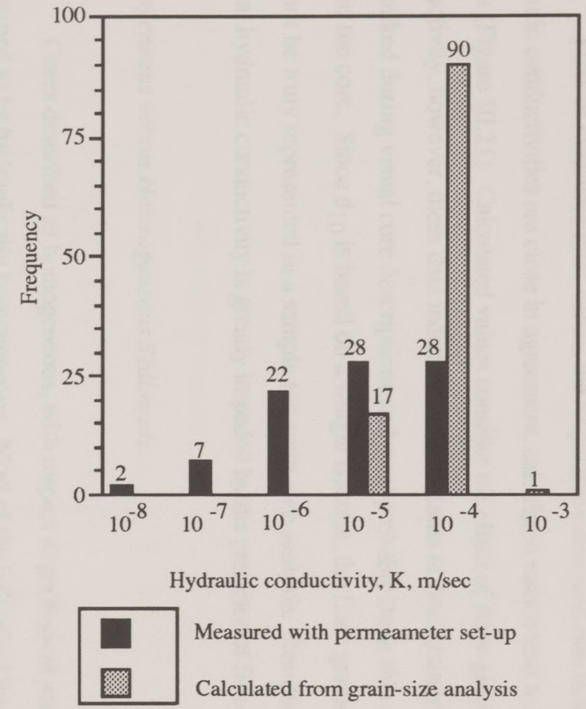


Figure III.20(b) Frequency and range of hydraulic conductivities.

020 with a range of 10^{-6} to 10^{-4} m/s. Within a 1.5 m core length, the largest range was calculated at well location 020, depth of 7.6-9.1 m having a range of $1.21x10^{-6}$ to $1.44x10^{-4}$ m/s.

Plots of measured rates versus the respective calculated rate indicate that although hydraulic conductivities are close in agreement, calculated values tend to be higher than measured values (Figure III.21). Calculated values consider the effect of finer-grained sediments on hydraulic conductivity, however, these data indicate that thin seams of fine-grained sediment may have been overlooked during visual core descriptions and most probably these thin seams impede vertical flow in the core. Since d_{10} is based on a weight fraction, the finer grained (and lighter) sediment may not be truly represented in a sample for grain-size analysis. Results of these data indicate that vertical hydraulic conductivity is greatly impeded by the presence of fine-grained sediments.

Homogeneous versus Heterogeneous Sediments

Cores described as homogeneous, with respect to geological sediments, were also determined to be hydraulically homogeneous. Most of the individual hydraulic conductivities at different depth intervals did not vary more than an order of magnitude. At well locations 020, depth of 0-1.5 m, and 982, depth of 4.5-6.1 m, measured hydraulic conductivities did not vary outside an order of magnitude (Appendix A5 and Table III.2). Calculated hydraulic conductivities for homogeneous cores range over less than an order of magnitude.

Ranges of hydraulic conductivity in heterogeneous cores were on several orders of magnitudes. At well location 019, depth of 1.5-3 m measured hydraulic conductivities ranged from 10^{-7} to 10^{-4} m/s and calculated hydraulic conductivities ranged from 10^{-5} to 10^{-4} m/s (Appendix A5 and Table III.2).

Equivalent Vertical and Horizontal Hydraulic Conductivity

73% of the measured and 97% of the calculated equivalent vertical hydraulic conductivities were within the same order of magnitude as the equivalent horizontal hydraulic conductivity for the same location and depth interval (Table III.2). 73% of the equivalent vertical hydraulic conductivities from measured hydraulic conductivities were within the same order as the measured whole core hydraulic conductivity of the same location and depth interval (Table III.2). 67% of the equivalent horizontal hydraulic conductivities were larger than the equivalent vertical hydraulic

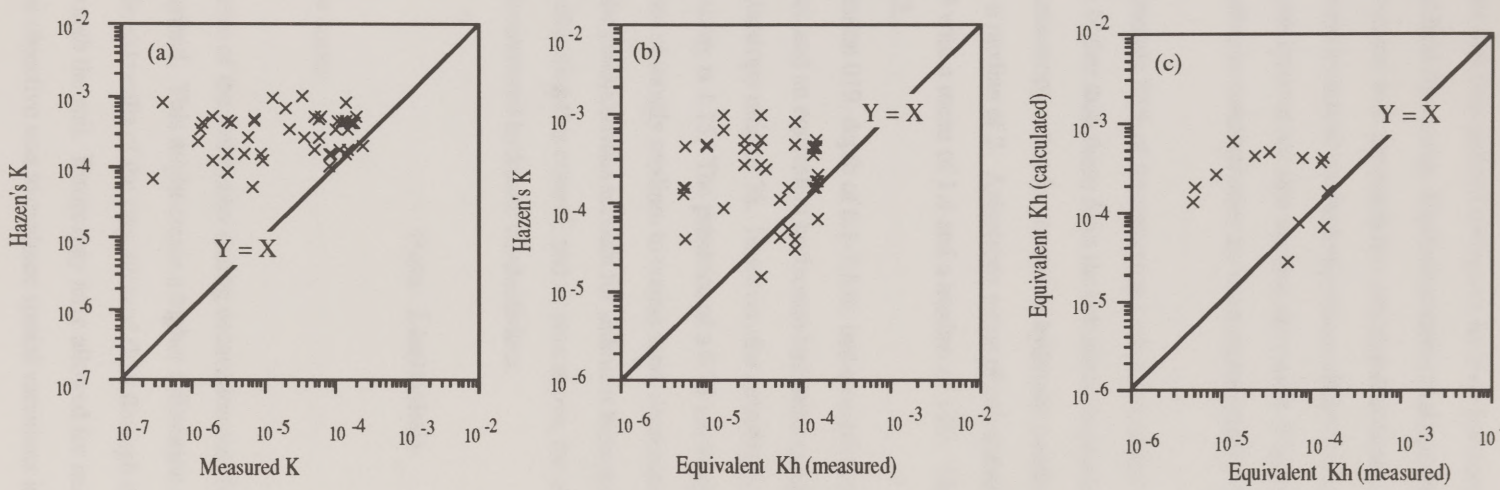


Figure III.21 Comparisons of hydraulic conductivities; (a) Calculated (Hazen's) hydraulic conductivity (51 samples) versus measured (permeameter) hydraulic conductivity and (b) equivalent horizontal hydraulic conductivity from measured rates and (c) equivalent horizontal hydraulic conductivity (measured) versus equivalent horizontal hydraulic conductivity (calculated).

conductivities for the same location and depth interval (Table III.2).

The effect that fine-grained sediments have on horizontal flow rates is not quite as drastic as the effect on vertical flow rates. Equivalent horizontal hydraulic conductivity of measured rates are in a close agreement with the respective calculated hydraulic conductivity (Figure III.21(b)). Equivalent horizontal hydraulic conductivity values obtained from measured and calculated methods from the same depth interval are also in close agreement (Figure III.21 (c)). These data suggest that calculated hydraulic conductivities are most representative of horizontal hydraulic conductivities.

Approximately 85% of the anisotropy ratios calculated from measured hydraulic conductivities are higher than those from the calculated hydraulic conductivities of the respective depth interval. Anisotropy ratios for measured hydraulic conductivities range from 0.77 to 76 with a mean of 15 and a median of 2. Anisotropy ratios of calculated hydraulic conductivities range from 0.44 to 6.89 with a mean of 1.4 and a median of 1.07. These results are shown in Appendix A5 and Table III.2.

Well location 019, depth of 6.1-7.6 m, had an equivalent vertical hydraulic conductivity of 2.03×10^{-6} m/sec and an equivalent horizontal hydraulic conductivity of 1.55×10^{-4} m/sec, resulting in an anisotropy ratio of 76. However, the anisotropy ratio calculated using Hazen's hydraulic conductivity is 1.15. The presence of a 6.75 cm length of coarse sand with silt, within the 48 cm long core of mostly medium to coarse sand, decreases vertical flow to a large degree. Measured hydraulic conductivities account for sediment heterogeneity, but grain-size analysis may not take into consideration this control, and as seen above, the anisotropy is lower than predicted when compared to measured hydraulic conductivities.

Data Limitations

In Situ Infiltration Rates

Disturbance of the soil matter during excavation may have loosened up the soil near the edges of the soil island. This might create a higher infiltration rate. It is possible that problems with sealing off the sidewalls of the ring allowed flow through the space between the wall and the soil instead of through the soil. Errors may have allowed for inaccurately measured infiltration rates, however, the objective was to evaluate spatial variations in recharge.

Hydraulic Conductivity Measurements

Disturbances of the sample during drilling and transportation from Bemidji to Austin may have caused cracks in the sediments allowing for inaccurately measured hydraulic conductivity values. Due to time constraints, finer grained sediment may not have become saturated prior to measurements of hydraulic conductivity. Presence of air bubbles within the sediment reduces the cross sectional flow area, thereby lowering measured hydraulic conductivities.

The permeameter cell and marriotte bottle setup was tested for repeatability within 5% accuracy in order to determine if the setup was valid as well as tested to meet standards (ASTM 5084-90, 1990) for accurate representation of true hydraulic conductivity.

An error that may have caused a minor discrepancy between measured and calculated hydraulic conductivities is the use of 100 ($cm^{-1}s^{-1}$) for *C*, in Hazen's approximation, for all of the sediment samples, however, using up to 150 ($cm^{-1}s^{-1}$) for *C* was not significant enough to cause the resulting discrepancy. Thin fine-grained seams not detected during visual core descriptions were probably averaged into a large core sample when analyzed for effective grain diameter, thereby creating a lower hydraulic conductivity when measured and a higher value when calculated from particle-size analysis. Although cores were divided into lithologically different units based on texture determined from visual core descriptions, it is possible that a few very small silt and very fine sand layers were over looked.

Water Level Measurements

Water level records were taken with different equipment by a variety of people. Measurements with the Epic® electric sounder could be reproduced within 0.001 m, however, when the *cut-and-tape* method was used, measurements were not as reliable. Land surface elevations are continuously updated due to faulty equipment and operator error. It is highly possible that the latest survey of wells, completed after this study, has uncovered more incorrect elevations.

IV. DISCUSSION

The parameters controlling groundwater flow are topography, glacial stratigraphy, hydraulic characteristics of the surficial sediments, and the climatic conditions in the area. Small depressions, such as *lake "1386"*, the kettle, and wetland, form the topographic relief at the site and express the glacial activity which formed the hummocky terrain. Vegetation and soil types control recharge amount and location.

Groundwater Response

Groundwater Hydraulic Conductivity

The results of visual core descriptions and particle size analysis indicated a wide range of material composition, size, and sorting exists within the site boundaries. Hydraulic conductivity is highly variable and ranges over 6 orders of magnitude (Table IV.1).

The hydrologic values determined for the homogeneous sediments indicated that individual (layer) hydraulic conductivities were on the same order of magnitude as the equivalent vertical hydraulic conductivity, as were the equivalent vertical and horizontal hydraulic conductivities (well 982, depth of 4.6-6.1 m and well 020, depth of 0-1.5 m). Throughout most of the site, individual layers in the heterogeneous sediments are usually not on the same order of magnitude as the measured whole core hydraulic conductivity. Sporadically placed thin fine-grained silt units (well 019, depth of 1.5-3 m) cause lower equivalent vertical hydraulic conductivities.

Anisotropy ratios of equivalent hydraulic conductivities, ranging from 0.44 to 76 with a mean of 15, suggests that flow varies to a wide degree throughout the entire site. The dominant flow component is horizontal throughout most of the site, especially on the northern flank of the kettle (well 019). A few locations indicate a dominant vertical flow component at varying depths north of the wetland (wells 980, 982, 983, 984, 020, and 021).

Aquifer properties cover a wide range of values (Stephenson et al., 1988). Although

Table IV.1

	Intrinsic Permeability, k, cm^2	Hydraulic Conductivity, K, m/s	Vertical Anisotropy	Darcian Velocity, u, m/day	Method used
Baehr and Hult (1989)	[a] $km=4.1 \times 10^{-9}$ $kx=3.7 \times 10^{-7}$ $kz=1.5 \times 10^{-7}$	2.8×10^{-4}	2.5		Air-phase permeability using pneumatic test in unsaturated zone
Bilir (This study)	[b] $5.7 \times 10^{-11} - 3.15 \times 10^{-7}$ [c] $1.66 \times 10^{-8} - 1.57 \times 10^{-6}$	[b] $5 \times 10^{-8} - 2.75 \times 10^{-4}$ [c] $1.44 \times 10^{-5} - 1.37 \times 10^{-3}$	[b] 0.8 - 76 [c] 0.4 - 6.9		Grain size analysis, and permeameter
Coontz (1990)	$1.3 \times 10^{-8} - 2.6 \times 10^{-8}$	$1 \times 10^{-4} - 2 \times 10^{-4}$		0.065 - 0.143	Water levels and flow model results
Essaid and Coontz (1991)	$5.7 \times 10^{-8} - 3.25 \times 10^{-7}$	$4.4 \times 10^{-5} - 2.5 \times 10^{-4}$	3, 3.4		Aquifer pump test at wells 310 and 602
Franzi (1988)	[d] $5 \times 10^{-8} - 2.7 \times 10^{-7}$ [e] $2 \times 10^{-15} - 9.9 \times 10^{-12}$	[d] $5 \times 10^{-5} - 2.7 \times 10^{-4}$ [e] $2 \times 10^{-12} - 9.9 \times 10^{-9}$			Grain size analysis
Miller (1988)	$4 \times 10^{-8} - 2.75 \times 10^{-7}$	$3 \times 10^{-5} - 2.1 \times 10^{-4}$			Flow model results
Pfannkuch (1979)		1.8×10^{-3}, 1.5×10^{-3}, 1.2×10^{-3}		0.3, 0.4, 0.5	Point dilution method
Siegal and Franzi (1984)		4×10^{-5} 2.7×10^{-4}		0.01 - 0.07	Grain size analysis
White (1991)	$2.19 \times 10^{-7} - 3.15 \times 10^{-6}$	$1.9 \times 10^{-4} - 5 \times 10^{-3}$		0.034 - 2.2 0.036 (mean)	Point dilution method

a km, kx, and kz are the layer, horizontal , and vertical bulk permeabilities, respectively.
b Values determined using a lab permeameter.
c Values determined using grain size analysis.
d Stratified drift units
e Lacustrine sediments

glacial drift aquifers are commonly characterized as homogeneous, it is clear that with the range and distribution of hydrogeologic parameters at the site, the aquifer is heterogeneous. Large horizontal flow components dominate the hydrologic system, however, local heterogeneities create reversals in the dominant flow direction.

Groundwater Flow

The Bemidji research site is a local recharge-discharge system, which is affected by climatic conditions and glacial stratigraphy. Seasonal and annual fluctuations in precipitation, temperature, and evapotranspiration create perturbations in the flow field, especially in topographically low areas where the water table is near the land surface. The characteristics of the glacial stratigraphy control the storage and transmission of groundwater.

Influence of Climatic Conditions

Variations in water table elevation were closely correlated with seasonal fluctuations in recharge and evapotranspiration. Larger fluctuations and greater climatic influence was observed in areas of shallow water tables, such as the kettle and wetland. This would suggest that yearly or seasonal fluctuations in rainfall, temperature, and evapotranspiration rates cause large fluctuations in the flow field. Over the last 5 years, however, the dry seasons have lowered the water table, probably decreasing the effect of local topography. Although fluctuations of up to 0.5 m were measured in the flow field at the wetland, larger fluctuations might be expected under normal annual climatic conditions.

The relationship between evapotranspiration and recharge is complex. Rainfall amounts are high in the summer when evapotranspiration is also at a maximum. Only small amounts of rainfall recharge the aquifer within the site boundaries during this time. Short storm events also recharge the aquifer in the spring and autumn, when evapotranspiration is low. Winter precipitation falls as snow and recharges the aquifer during the spring as snowmelt. These climatic extremes are portrayed in the local groundwater system.

In times of precipitation and associated high recharge two areas of focused recharge are located in the kettle and the wetland. Mounding occurs in the wetland and kettle area throughout most of the year, however, these conditions may alter when high evapotranspiration rates influence recharge. Groundwater then flows out of these areas and converges with the regional flow direction. Smaller fluctuations occur in the surrounding sediments, most commonly near oil pools, contaminant plumes, and in the *spray zone*. During times of low recharge and a deep water table, the water table is less affected by the influences of evapotranspiration.

Influence of Stratigraphy

The hydrostratigraphy is a significant control of the local groundwater flow due to the presence of several finer-grained discontinuous layers that represent hydrologic discontinuities. Groundwater flow is fast through large-grained sediments in the outwash, but within the outwash sediments there are fine-grained layers, which slow groundwater and create local flow heterogeneities imprinted on the regional groundwater system. Several reversals occur in the vertical flow field. These areas often coincide with the location of a fine-grained silt layer near or below the water table.

In the *spray zone*, depressions and mounds occur in the water table (wells 523 and 707) and probably result from the heterogeneity of sediments. I suggest two explanations for the response seen in these wells. First, consider a high water table where wells 523 (screen located in the silt layer) and 707 (screen located slightly below the silt layer) have water levels that are similar to other wells in the surrounding sediments. As the water table falls, downward flow through the silt layer is slow and practically impeded. Water ponds on the silt layer, mimicking the previously higher water table. Water levels in well 523 would be higher than in well 707, indicating downward flow. Equilibration of the water levels to the normal water table in the surrounding sediments eventually occurs and then recharge to the aquifer causes a rise in the water table. Vertical flow through the silt layer is slower than normal and the equilibration of the water table in well 523 to the actual level is delayed. Water levels in well 707 would register higher than in well 523, indicating confined behavior. If this was the case, a depression would not occur in the drier seasons. In actuality, the response seen is reversed, lower levels are seen in well 707 than in well 523. This process gives a credible explanation for mounding, however, it does not give support for the depressions actually seen in the water table.

The second and more likely process is based on the combination of the unconfined aquifer being recharge-dominated and the low hydraulic conductivity of the fine-grained silt. The rising and falling of the water table when near the silt layer is controlled by the hydraulic conductivity of the silt layer. Recharge to the aquifer at the silt layer mounds water on top of the unit. Since the *spray zone* has a semi-impermeable "membrane" of oil-coated sediments, recharge in this area is commonly small. The water moves through the silt at a much lower rate than that of the surrounding sediments. At times of low recharge, water moves slowly through the silt layer and either does not reach the water table or is delayed recharge. The silt layer acts as a barrier to downward flow and during low recharge seasons or events, a depression forms at the water table. Water levels in the wells do not have confined behavior. It is likely that this process occurs throughout the site on differing scales. Silt layers not yet detected may be causing some of the other perturbations in the flow field.

Although the water table typically forms a groundwater mound in the kettle area, piezometric data indicate upward vertical gradients, which usually support a discharge point or depression in the water table. Heads in a few wells exhibit confined behavior, a theory that has not been applied to the site in the past. However, if we examine in detail the flow direction between wells and the exact location of the water table mound, a solution to the discrepancy is possible. I suggest that a silt layer approximately 3 - 9 m below the land surface is causing the response of the heads in the kettle.

It is possible that the silt layer acts as a local confining unit, separating two aquifers, and retarding downward flow into the lower aquifer. Heads in the well 702 series act confined with deeper wells exhibiting higher heads than those in shallower wells located above the silt layer. Water in well 701a is "clean" and indicative of recharge water. The low hydraulic conductivity of the very fine silt, and possibly till (well 019, below 422.28 m, msl), forces recharge water to build up and form a perched groundwater mound in the upper aquifer. However, this theory is not supported by geochemical data and the fact that there is downward flow at the well 702 series during some times of the year (Bennett, personal communication, 1992).

A more likely solution is that a small recharge-discharge system is present within the kettle (Figure IV.1). Well 701a (located at the lowest point in the kettle) is a point of focused recharge, receiving all of the runoff from snowmelt and precipitation events. During snowmelt, overland flow transports all of the surface water into the kettle and enters the unsaturated zone at the lowest point in the kettle. At this location, recharge forms a groundwater mound that recharges to the aquifer. Water table maps, piezometric and geochemical data support this response displayed at well 701a.

Beneath the kettle, deeper in the aquifer, regional flow is upward, creating a small

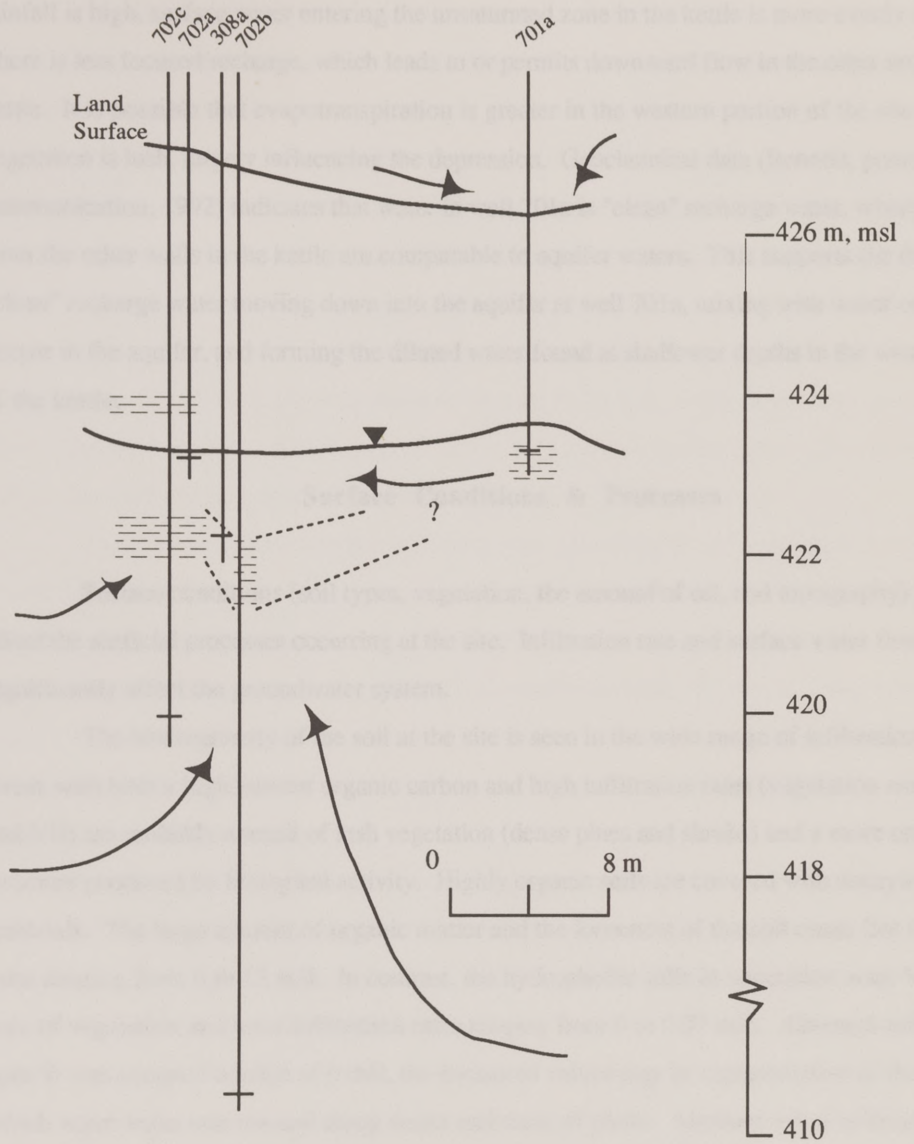


Figure IV.1 Possible flow pattern underneath kettle. Location of wells and screen depths are shown. Arrows indicate groundwater flow lines. Hacthed pattern represents silt unit at 3-9 m below land surface.

discharge zone in the western portion of the kettle. During the warmer times of the year, when rainfall is high, surface water entering the unsaturated zone in the kettle is more evenly distributed. There is less focused recharge, which leads to or permits downward flow in the other areas in the kettle. It is possible that evapotranspiration is greater in the western portion of the site, where vegetation is lush, largely influencing the depression. Geochemical data (Bennett, personal communication, 1992) indicates that water in well 701a is "clean" recharge water, whereas, waters from the other wells in the kettle are comparable to aquifer waters. This supports the theory of "clean" recharge water moving down into the aquifer at well 701a, mixing with water originating deeper in the aquifer, and forming the diluted water found at shallower depths in the western portion of the kettle.

Surface Conditions & Processes

Surface conditions (soil types, vegetation, the amount of oil, and topography) strongly affect the surficial processes occurring at the site. Infiltration rate and surface water flow significantly affect the groundwater system.

The heterogeneity of the soil at the site is seen in the wide range of infiltration rates. Areas with both a high percent organic carbon and high infiltration rates (vegetation zones I, II, and VII) are probably a result of lush vegetation (dense pines and shrubs) and a more open soil structure produced by biological activity. Highly organic soils are covered with decaying plant materials. The large amount of organic matter and the looseness of the soil cause fast infiltration rates ranging from 6 to 13 m/d. In contrast, the hydrophobic soils in vegetation zone V are almost bare of vegetation and have infiltration rates ranging from 0 to 0.07 m/d. Although infiltration zone D was assigned a value of 0 m/d, the measured values may be representative of the rate at which water leaks into the soil along stems and roots of plants. Medium value infiltration rates are indicative of undisturbed soils covered with grass and small pine saplings. Soil structure is tighter without the presence of organic matter and cause slower infiltration rates than the soil in the wooded areas.

Water table depressions in the kettle and wetland areas are probably caused by an increased amount of evapotranspiration, which lowers the net recharge available to the aquifer at these points. The water table is probably influenced by the presence of high consumptive use trees (aspen and birch). These trees consume a large amount of water. During low rainfall seasons, excess water may be consumed before reaching the water table thereby creating less recharge to the aquifer. During normal to high precipitation seasons, when the water table is shallow, within the rooting zone, vegetation consumes water from both the water table and from rainfall infiltrating the unsaturated zone.

In areas with very low infiltration rates, the amount of oil on grain surfaces can be related to the low permeability of the soil. The higher the amount of oil, the lower the ease of flow of water through and into the soil matter. Hult (personnel communication, 1991) suggests a "Gore-Tex® effect" is acting in the *spray zone*. The oil material on the surface and in the top foot of soil acts as a semi-permeable "membrane", allowing for transfer of vapor only. If water should be below this cap of oil, it can only move downward to the water table or as vapor upward and out. Gases can move up and out of the soil as well as into the soil, however, liquid is pooled on the soil surface and repelled, much as rainwater is on a Gore-Tex® rain jacket.

Surface-water flow is redirected on the impermeable soils and hummocky terrain to locally focused points of recharge. Depressions, such as the kettle, wetland and *lake "1386"*, receive runoff from surrounding areas as do the low-lying areas surrounding the *spray zone*, which receive all the rain falling onto and running off of oil-covered sediments. Where the water table is close to the ground surface, focused evaporation in the unsaturated and saturated zone occurs and water levels respond quickly to local climatic changes. Water levels are most likely to fluctuate to a larger degree in these areas.

Currently eroding areas in the *spray zone* may eventually return to the pre-contaminated rates. Zones characterized by low infiltration and high oil content may eventually obtain a higher infiltration rate as the semi-permeable "membrane" is weathered and eroded. Areas formerly characterized by clean sands and high infiltration rates may become covered by oily sediments that eventually lower the infiltration rate.

Natural variabilities in infiltration rates and the presence of oil on surficial sediment, in the *spray zone* causes variabilities in recharge rates. Recharge rates are usually calculated from water level rises in wells and applied to an entire site. Even on the small scale at the Bemidji site, this is not a good representation of temporal and spatial variations in recharge rate. Variabilities result not only from the added influence of oil on grain surfaces in the *spray zone*, but from natural sediment and vegetation differences and micromorphology of the land. Although landforms (kettles, lakes, and wetlands) are of low relief, they significantly affect the hydrologic system.

V. GROUNDWATER MODELING

Steady-State Areal Model

This section includes a detailed methodology of model design, selection of initial conditions, calibration, and verification. The steady-state model is used to generate a simplified view of hydraulic heads under the assumptions of constant recharge and evapotranspiration in an isotropic and heterogeneous aquifer with fixed boundaries through time. A copy of MODFLOW 3.2 (McDonald and Harbaugh, 1988) was compiled, and modified for compatibility on a Sun SPARCstation™ SLC workstation®. Simulated water levels were contoured using MATLAB™ (SunOS™) and Surfer® (MS-DOS®).

Model Area and Grid Design

Preparation for model simulations involved determining the modeled area, type and location of model boundaries, grid design, grid mesh size, and aquifer characteristics. The model grid has dimensions of 640 x 700 m with the long dimension of the grid aligned along N37.7°E-S37.7°W (Figure V.1). The model design is a variable grid of 20 and 40 m wide blocks, creating a 22-column by 30-row by one-layer of blocks. The smaller cells are focused in the kettle, spray zone, and wetland. The SIP solution technique was used with maximum iterations for closure of 50, an acceleration parameter of 1, and a convergence criteria for hydraulic head change of 0.001 m.

Initial Conditions

A constant head boundary was designated along the shoreline of *lake "1386"* (Figure V.1). No-flow boundaries are located along the northern and southern borders of the modeled area, parallel to the general groundwater flow direction. A small section along the southern no-flow boundary is designated as a flow boundary. A topographic high, located south of the wetland, defines the

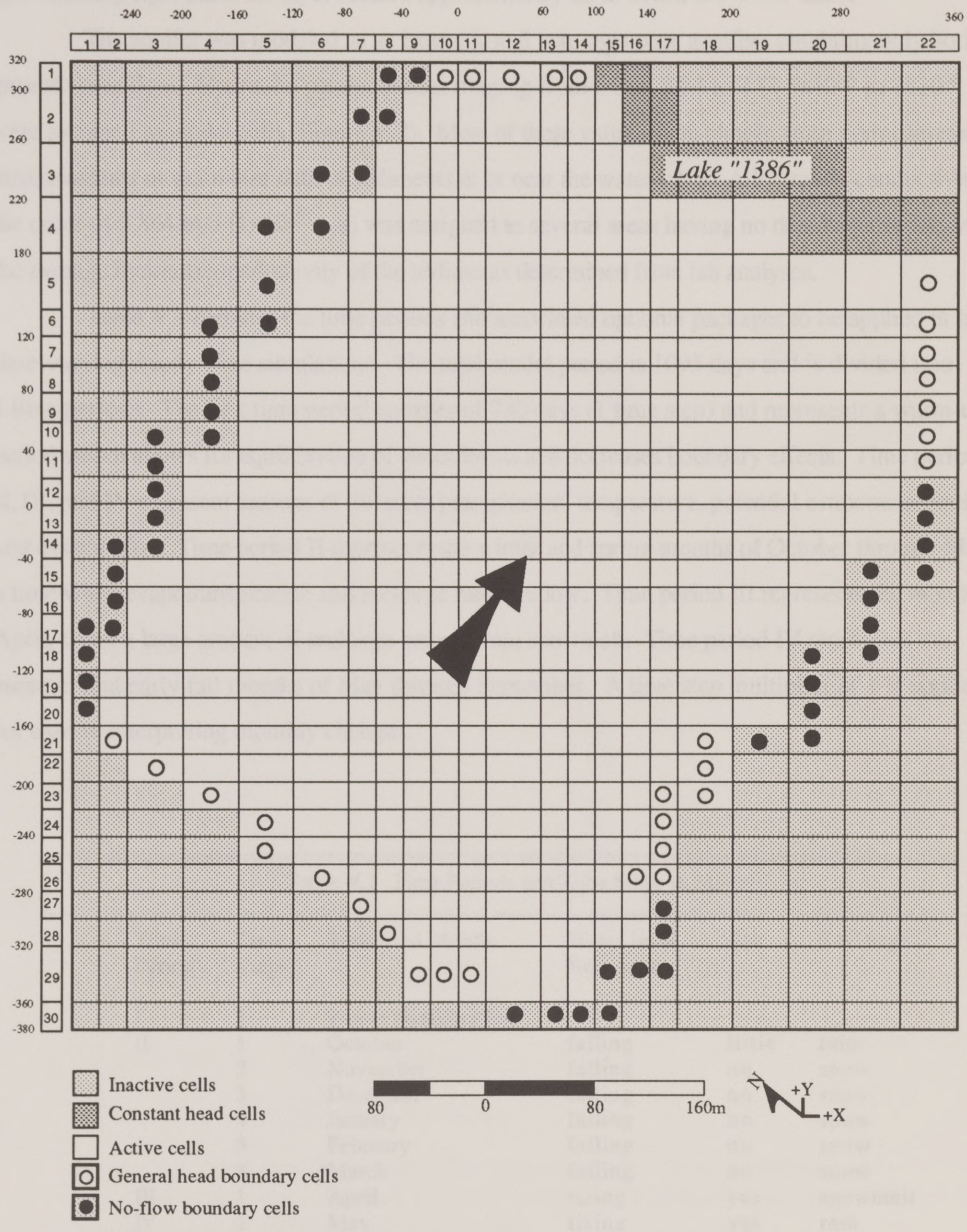


Figure V.1 Initial boundary conditions, Design A. Numbers listed along outside edge of row and column numbers are referenced from the grid system shown in all previous site maps. The large arrow indicates general groundwater flow directions.

westernmost edge of The southern border. The bottom boundary of the modeled area is a hydraulically tight basal till layer located approximately 25 m below the water table.

The aquifer was modeled as an isotropic and heterogeneous aquifer containing only horizontal groundwater flow. Hydraulic conductivities ranging from 0.3 to 8.64 m/d (3.5×10^{-6} to 1×10^{-4} m/s) were assigned to model cells (Figure V.2). Most of these values were chosen from permeameter measurements or grain-size data of sediments at or near the water table. A hydraulic conductivity on the order of 0.864 m/d (1×10^{-5} m/s) was assigned to several areas having no data because this value is the average hydraulic conductivity of the sediments determined from lab analyses.

Table V.1 displays the time periods and associated optional packages to be applied in later time-varying steady-state simulations. The total model period is 1095 days and is divided into 4 time periods. The first time period consists of 730 days (1 time step) and represents a warm-up period which allows for equilibration of water levels and decreases boundary effects. Time periods II, III, and IV represent seasons of different precipitation, temperature, potential evapotranspiration, and evaporation. Time period II represents the winter and spring months of October through May, a time when evapotranspiration and recharge rates are low. Time period III represents the month of April, when a large amount of recharge occurs from snowmelt. Time period IV represents the summer and early fall months of May through September. A time step multiplier of 1 is applied for ease in interpreting monthly changes.

Table V.1 Time Periods and Time Steps in Model

Time Period	Time Steps	Simulated Month	Water level Response	*Etp*	Recharge
I	1	2 year equilibration			
II	1	October	falling	little	rain
	2	November	falling	no	snow
	3	December	falling	no	snow
	4	January	falling	no	snow
	5	February	falling	no	snow
	6	March	falling	no	snow
III	1	April	rising	yes	snowmelt
IV	1	May	rising	yes	rain
	2	June	rising	yes	rain
	3	July	peak	yes	rain
	4	August	falling	yes	rain
	5	September	falling	yes	rain

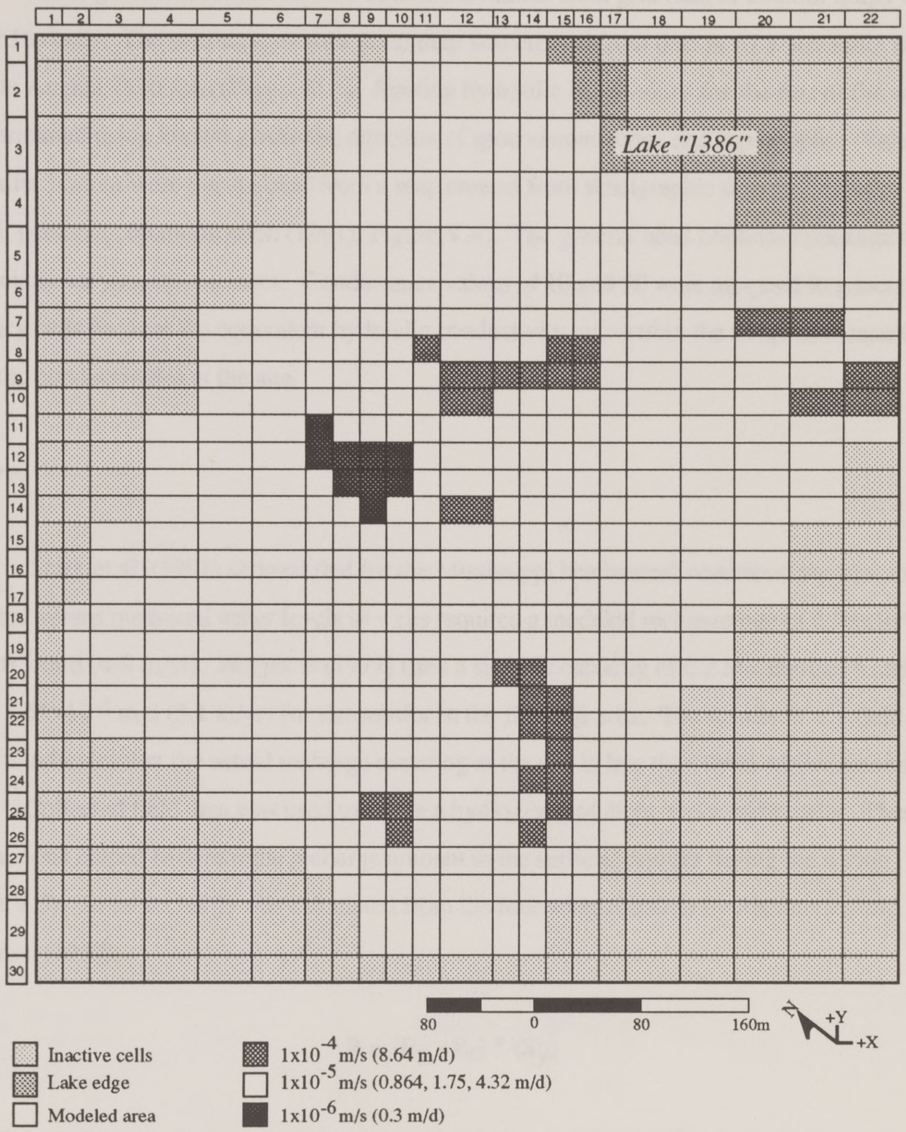


Figure V.2 Areal distribution of hydraulic conductivity. Data is based on stratigraphic data collected from grain size analysis and lab permeameter measurements of sediments at the water table.

Starting Water and Aquifer Bottom Elevations

Starting water level and aquifer bottom elevations from grid files of contour maps were assigned to cells. The starting hydraulic head map was created from data in 67 water table wells from the August 1990 data (Figure V.3). Starting hydraulic head values for the rest of the area were estimated using known gradients, direction of groundwater flow, and topography. Values for the aquifer bottom were interpolated from a map created from stratigraphic data in 19 wells (Franzi, personal communication (1991); Figure V.4). The general head boundary package allows for spacially varying conductance. Conductance values of 10 and 20 were assigned to general head boundary cells because the equivalent hydraulic conductivity was within the range of measured hydraulic conductivities at the site.

Recharge

Stark et al. (1991) showed that for the Mississippi headwaters watershed the best match of simulated versus measured water levels in wells required a modeled recharge rate of 2.78×10^{-4} - 5.57×10^{-4} m/d (4-8 in/yr). Helgesen (1977) used a specific capacity of 0.2 to calculate a recharge rate of 3.55×10^{-4} m/d (5.1 in/yr) for the aquifer in the Bemidji area. The results of my field research indicates that the actual recharge occuring at the site is less than these earlier estimations.

Collected field data was used to create a hydrograph of eight water table wells. These constructions helped to determine recharge amount to the surficial aquifer during the spring (Figure V.5). Areal recharge was calculated from the following equation by Rasmussen and Andreasen (1959);

$$R = (E_p - E_r) * (S_y)$$

where R is recharge in inches, E_p is the elevation of the water level at peak stage, E_r is the elevation of the water level at the recession stage on the same day as the peak stage, and S_y is the specific yield of the surficial aquifer. Table V.2 shows representative specific yields for respective grain textures (Johnson, 1967) used in calculations for recharge.

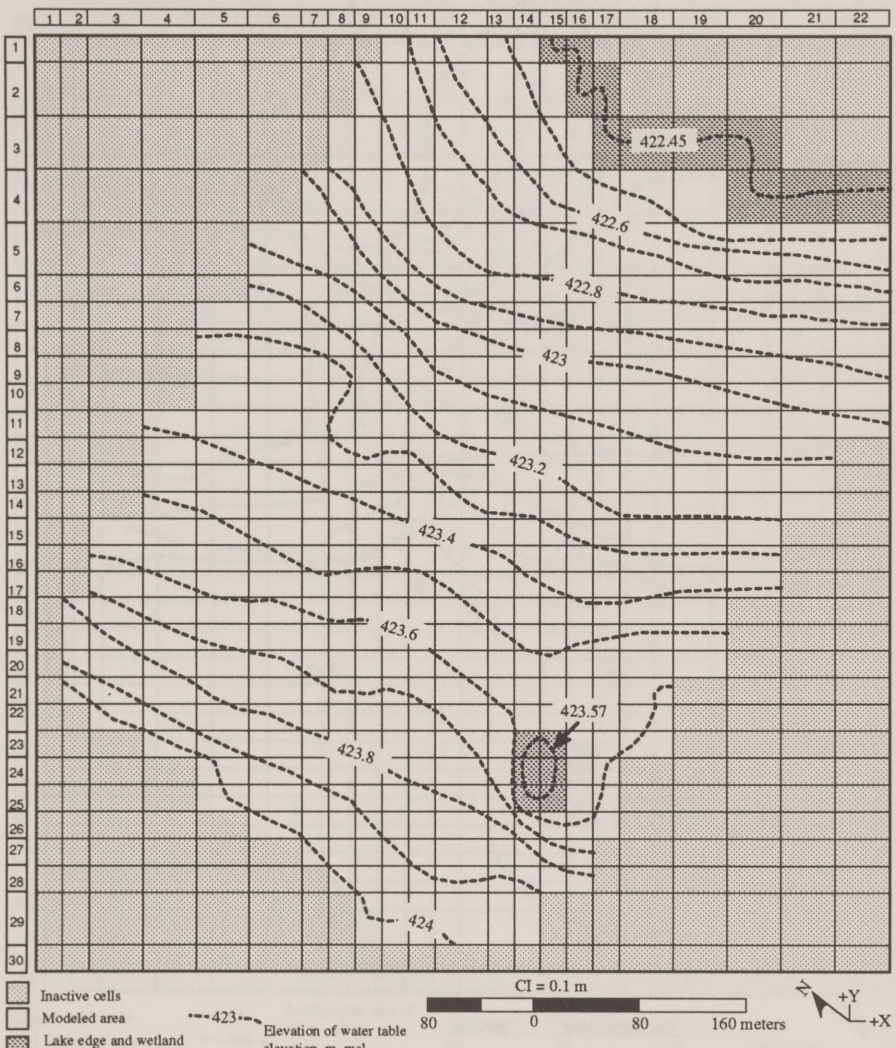


Figure V.3 Starting water table elevation (August 1990 data, see Figure III.15 for data collection wells)

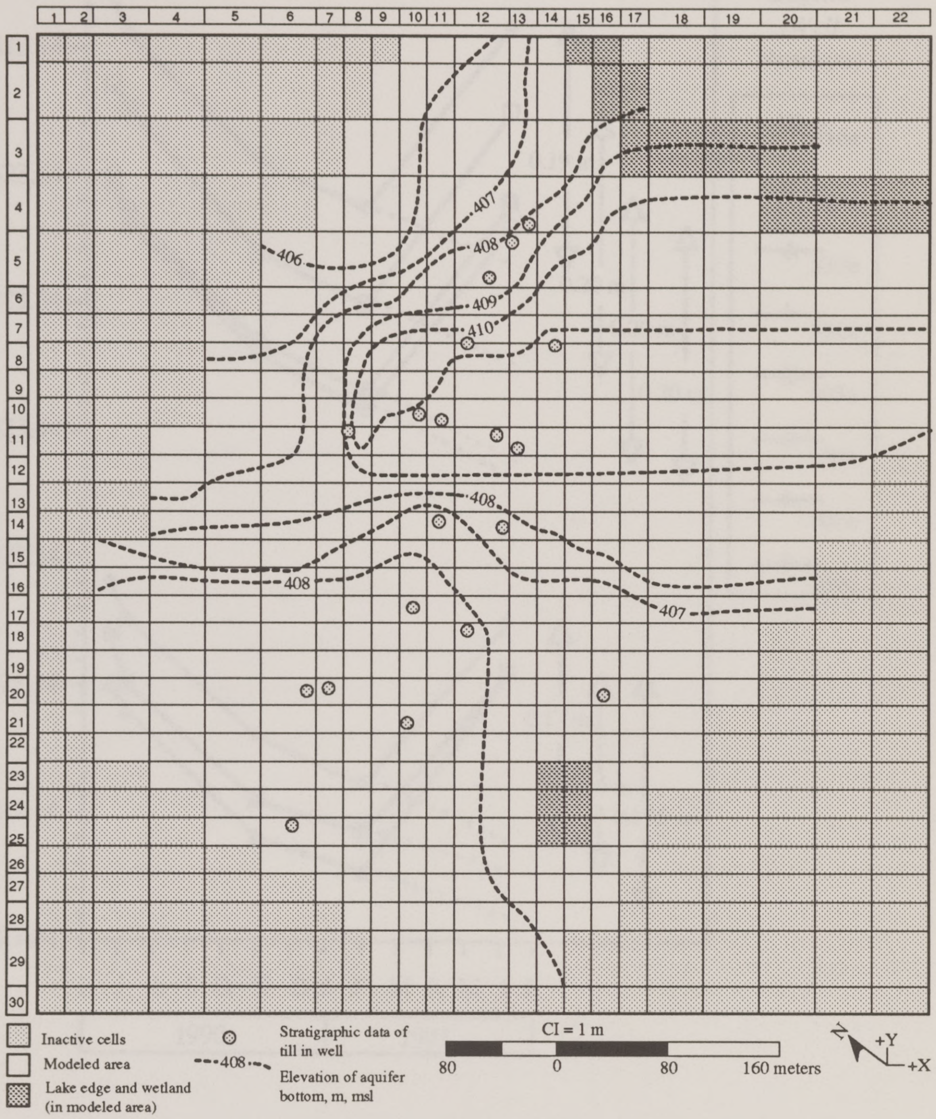
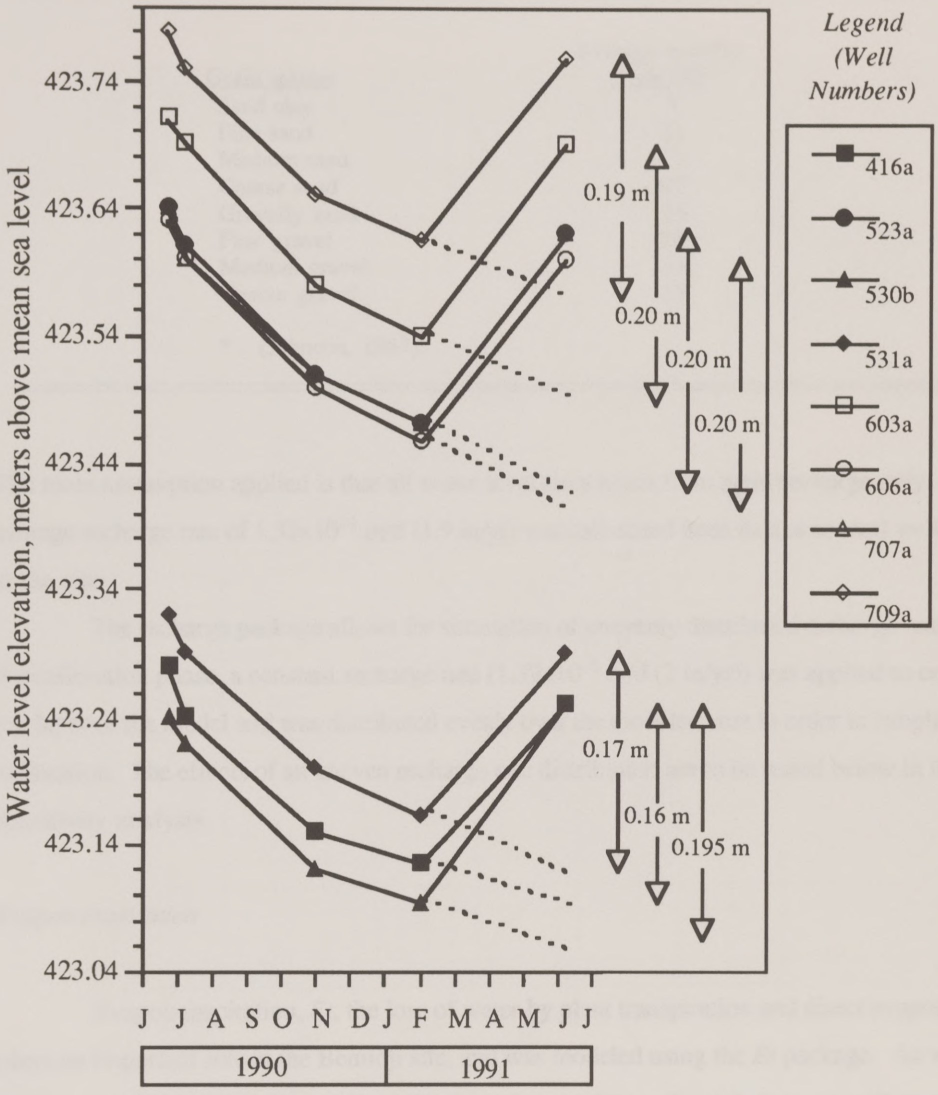


Figure V.4 Elevation and configuration of aquifer bottom (Contour lines modified from Franzi, personal communication, 1991)



Recharge = (water-level rise) * (estimated specific yield)
= (0.19 m) * (0.26)
= 1.9 inches

Figure V.5 Hydrograph method of estimating recharge to the surficial aquifer during the spring. Several observation wells at the site are displayed. The hydrograph indicates the rise and fall of water levels throughout the year. The recession curve, a portrayal of groundwater decline during periods of no recharge, is extrapolated to the date of peak stage.

Table V.2 Associated Specific Yields of Sediments

Grain texture	Average specific yield (%)
Sand clay	7
Fine sand	21
Medium sand	26
Coarse sand	27
Gravelly sand	25
Fine gravel	25
Medium gravel	23
Coarse gravel	22

* (Johnson, 1967)

The main assumption applied is that all water level rises result from areal recharge only. An average recharge rate of $1.32x10^{-4}$ m/d (1.9 in/yr) was calculated from data at several wells located at the site.

The recharge package allows for simulation of unevenly distributed recharge rates. For the calibration phase, a constant recharge rate ($1.39x10^{-4}$ m/d (2 in/yr)) was applied to cells in the top layer of the model and was distributed evenly over the modeled area in order to simplify calibration. The effects of an uneven recharge rate distribution are to be tested below in the sensitivity analysis.

Evapotranspiration

Evapotranspiration, *Et*, the loss of water by plant transpiration and direct evaporation, plays an important role at the Bemidji site, and was modeled using the *Et* package. As with the recharge package, this package allows for changing conditions through time, as well as unevenly distributed *Et* rates. This package takes into consideration three parameters, the *Et surface*, extinction depth, and maximum *Etp* (potential evapotranspiration rate).

Et from the aquifer occurs when the water table is within the rooting zone of vegetation and is greatest when the water table is at the land surface (Helgesen, 1977). The *Et surface* is the elevation at which maximum *Etp* occurs should the water table be at or above this elevation. Land surface represents the *Et surface* in this study. The *Et surface* was created from a grided file of

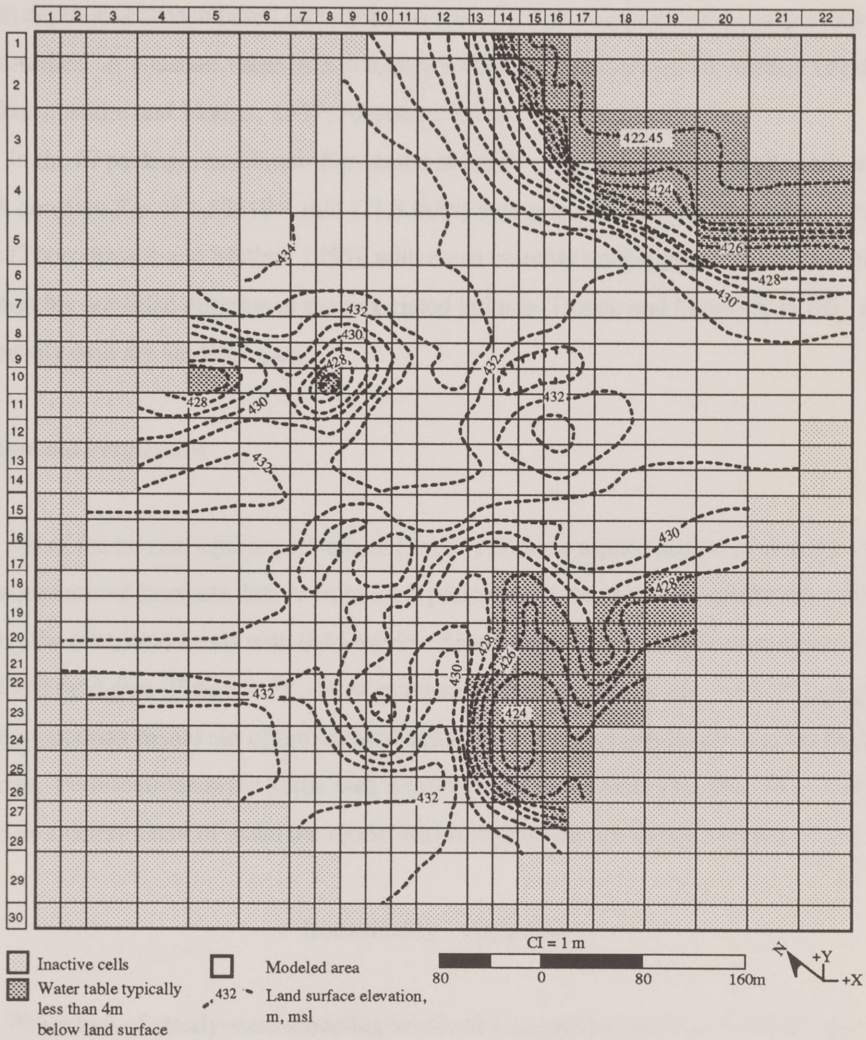


Figure V.6 *Et surface* (Elevation at which maximum evapotranspiration occurs if the water table is above this elevation) topography at the site and estimated for areas lacking topographic data (Figure V.6). Estimations were based on field observations and elevations of a few distant wells.

The extinction depth is the depth below the *Et surface* that *Etp* ceases. This value for the extinction depth was chosen based on vegetation type, field observations, and comparisons with previous studies. A constant value of 3 m agrees with studies completed for similar vegetation types (Thornthwaite and Mather, 1957; Johnston, 1970).

In the *Et* package, maximum *Etp* occurs at the *Et surface* and decreases linearly with depth. A constant *Etp* of 1.52×10^{-3} m/d (21.8 in/yr) was calculated, using Thornthwaite's equation (Thornthwaite and Mather, 1955), with mean monthly temperatures and a correction factor for the monthly sunshine duration at the associated latitude (Dunne and Leopold, 1978). *Etp* was applied evenly over the modeled area.

Calibration and Verification

All of the chosen aquifer parameters (Table V.3) were representative of realistic values and had been determined from site data or from local precipitation records. The model was calibrated by comparing the simulated heads with field results. Simulated hydraulic heads compared well against August 1990 field data (Figure V.7) . Flow gradient increased towards *lake "1386"*, as seen in field data. Flow occuring in and out of the wetland and kettle showed a reasonable view of local flow phenomena. Perturbations in the kettle area were depicted in simulated results. Flow rates were also used as a determinant of when the model was ready for the sensitivity analysis (Table V.4).

Sensitivity Analysis

Phase two of steady-state modeling involved a sensitivity analysis, in which the influences of time-constant and time-varying model parameters were determined. The time-constant analysis focuses on determining the effects of elevation and configuration of the aquifer bottom, evenly and unevenly distributed recharge and *Etp* rates, conductance values, boundary conditions, hydraulic conductivities, heterogeneity in the flow field, convergence criterion, and response to water levels in the wetland and *lake "1386"*. A changing hydrologic budget with time-varying parameters, recharge and evapotranspiration, is simulated in a series of steady-state models.

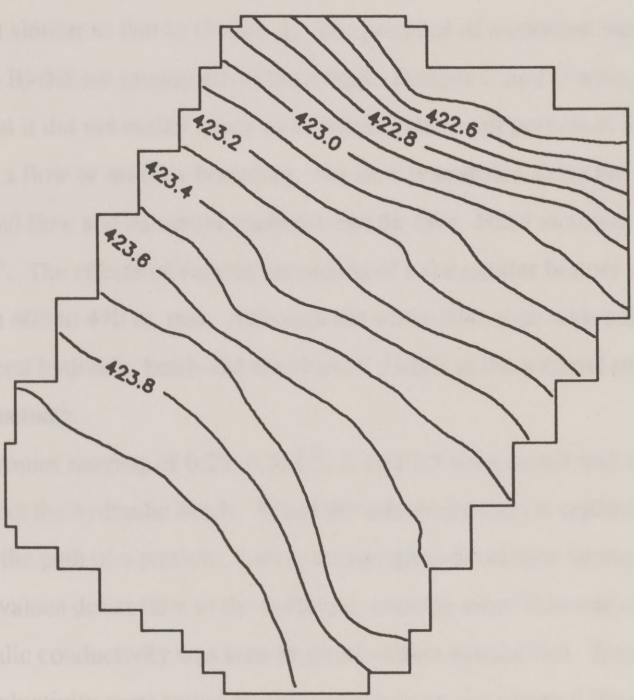
Table V.3 Parameters chosen from Calibration Phase

AQUIFER PARAMETERS	
Boundary conditions	Design A
Aquifer bottom	Variable configuration 406-410 m, msl
Initial head	August 1990 data 422.45-424 m,msl
Anisotropy	1 (K_{row}=K_{column})
Hydraulic conductivity	Variable grid with 0.3-8.64 m/d (10^{-6}-10^{-4} m/s)
General head boundary conductances	20 (except for section south of wetland=10)
Potential evapotranspiration rate	1.52×10^{-3} m/d (21.8 in.yr)*
Et surface	Land surface elevation 422.45-434 m, msl
Extinction depth	3 m
Recharge	1.39×10^{-4} m/d (2 in/yr)*
SOLUTION PARAMETERS FOR SIP	
Maximum iterations for closure	50
Acceleration parameter	1
Convergence criteria	0.001 m

* Value is evenly distributed over modeled area and is constant during model.

Table V.4 Resulting Rates (m^3/d) from Calibration Phase

IN:		OUT:	
STORAGE =	0.	STORAGE =	0.
CONSTANT HEAD =	0.	CONSTANT HEAD =	20.852
RECHARGE =	36.418	RECHARGE =	0.
ET =	0.	ET =	14.633
HEAD DEP BOUNDS =	12.273.	HEAD DEP BOUNDS =	13.165
TOTAL IN =	48.691.	TOTAL IN =	48.680
IN - OUT =	0.11055E-01	PERCENT DISCREPANCY =	0.02



1 inch = 187 meters

Figure V.7 Simulated heads—Calibration phase. Contour interval is 0.1 m. Water table elevation is in meters above mean sea level.

The time-varying analysis takes into consideration climatic changes and attempts to model how each influences the groundwater system.

Time-Constant Parameter Testing

<u>*Aquifer and Model Parameters*</u>

Boundary conditions were tested with different designs for general head and no-flow boundaries (Figure V.8; Table V.5). Results indicated that while boundary conditions did not greatly influence hydraulic heads, each created large discrepancies in the flow budget. Designs B and E were most similar to that in Design A. The presence of a constant head source at the wetland (Design B) did not greatly effect the model. Designs C and D were similar to Design A and indicated that it did not matter much as to whether the small portion of the boundary behind the wetland was a flow or no-flow boundary. No-flow boundaries along the north and southeast borders influenced flow and increased gradients into the lake. Head increases were larger in cells near *lake "1386"*. The effects of various elevations of a flat aquifer bottom were tested at 1 m increments from 405 to 410 m, msl. Although the water table rose with a shallowing aquifer bottom, the general hydraulic heads did not change. Heads in the wetland and along the southern border did not fluctuate.

Anisotropies ranging of 0.25, 0.5, 1.5, 2, and 2.5 were tested and were not seen to significantly effect the hydraulic heads. When the anisotropy ratio is applied, a preferred vector of flow influences the path of a particle. Lower anisotropies direct flow in the southeast direction, whereas higher values direct flow to the northeast, creating more flow out of the site.

Hydraulic conductivity was seen to greatly effect simulations. Evenly distributed values of hydraulic conductivity were tested at constant values ranging from 0.0864 to 21.6 m/d ($1x10^{-6}$ to $2.5x10^{-4}$ m/s). Simulations with hydraulic conductivities less than 8.64 m/d increased water levels by over 2 m. Larger hydraulic conductivities were seen to decrease heads by less than 1 m. Hydraulic head simulations with values lower than 0.864 m/d did not closely fit field data. A large depression typically formed in the wetland area. Simulations of hydraulic conductivity values higher than 2.16 m/d did not show any perturbations in the flow field and produced reasonably higher flow rates and volumes than the field data suggests. Overall, hydraulic gradients decreased to at least 0.0018.

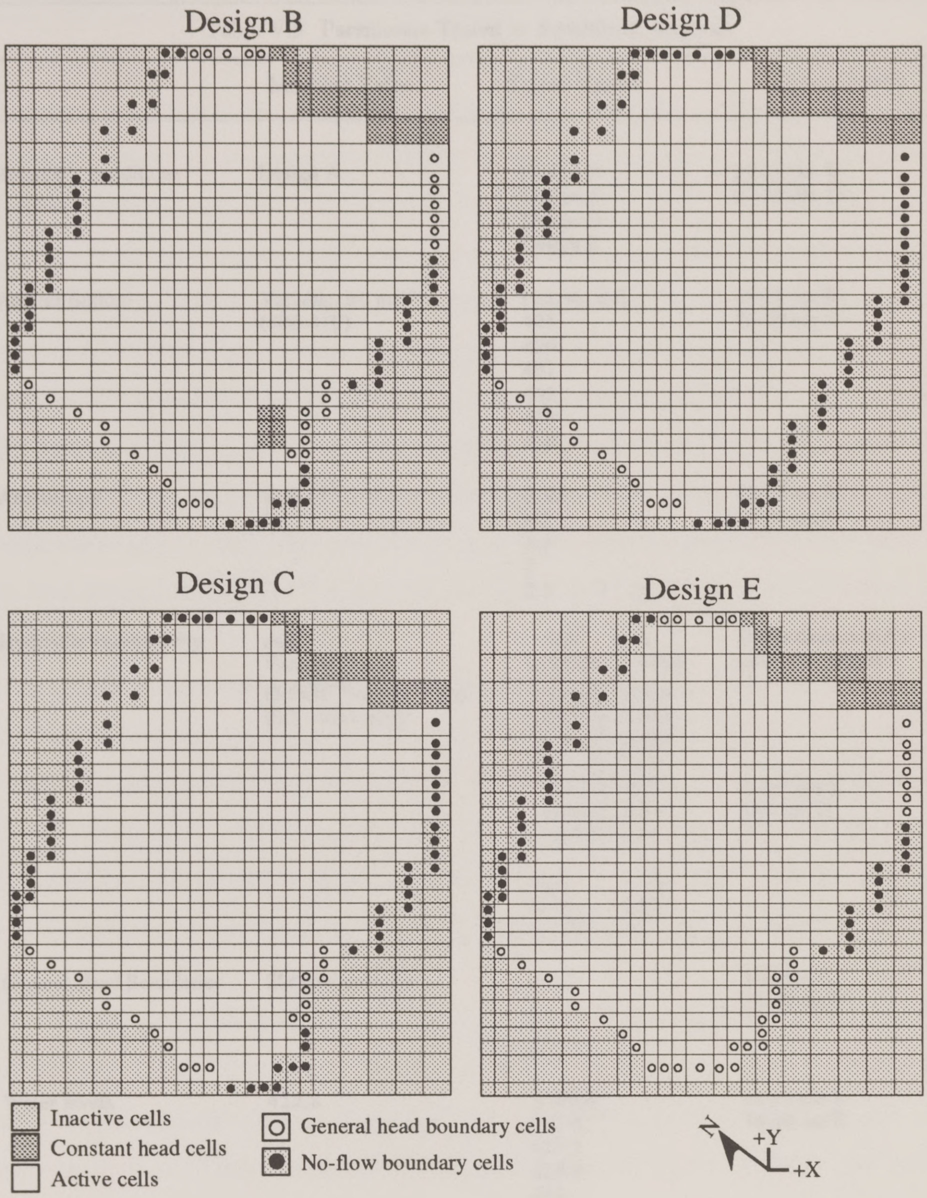


Figure V.8 Boundary conditions for testing in steady-state simulations

Table V.5 Parameters Tested in Sensitivity Analysis

	Modeled Value	Tested Values	Comments*3
Boundary conditions	Design A	Design B Design C Design D Design E	14-19 cm U 17-34 cm D
Aquifer Bottom	Variable, m, msl*2 (406-410)	Flat, m, msl 405 406 407 408 409 410	18-21 cm U 16-19 cm D
Anisotropy	Kc/Kr *1 1	0.25 0.5 1.5 2 2.5	15-25 cm U 10-30 cm D
Hydraulic conductivity	m/d Variable ($3.5x10^{-6}$-$1x10^{-4}$ m/s) (0.3 - 8.64 m/d)	m/s m/d 1.00E-06 0.0864 2.50E-06 0.216 5.00E-06 0.432 1.00E-05 0.864 2.50E-05 2.16 5.00E-05 4.32 1.00E-04 8.64 2.50E-04 21.6 mean 1.75 -st dev 0.25 +st dev 15	Heads decreased for rates < 4.32 m/d 5-137 cm U 2-49 cm D
General Head Boundaries	20(Wetland=10)	0.1 1 50 100	5-23 cm U 18-22 cm D
Water levels	422.8	Wetland 422.8 423.2 423.8 424	11-18 cm U 16-19 cm D
	422.45	Lake 422 422.2 422.8 423	15-25 cm U 3-65 cm D

*1 Kc = hydraulic conductivity of columns, Kr = hydraulic conductivity of rows

*2 m, msl = elevation in meters above mean sea level

*3 Range of simulated head change from field data. U=upgradient location, node (7,21) and D=downgradient location, node (17,6).

Various rates of conductance along general head boundaries were tested. Values along a boundary were changed as a unit in order to simulate even flow from outside the grid. Values of 0.1, 1, 50, 100 m/d were tested. Unreasonably low conductance values (0.1 - 1 m/d) were seen to greatly decrease gradient and hydraulic head in the simulated versions. Conductances of 50 and 100 m/d were seen to produce the same hydraulic head contour lines as the calibrated model and have a better mass balance.

The response of water levels in the aquifer to changes in the elevation of the wetland and *lake "1386"* was tested by setting water body elevations at various levels which are within the range of field data. Wetland levels ranged from 422.8 to 424 m, msl and *lake "1386"* levels ranged from 422 to 423 m, msl. The general flow patterns were not influenced to a significant degree. However, small perturbations in hydraulic heads were removed when high water levels were simulated. All simulated flow patterns in the wetland runs were compatible with those of the calibrated model. In fact, a few simulations more closely resembled the field data than results from the calibrated model.. Higher water levels in the wetland produced reasonable flow rates and flow gradients.

Lake level simulations were run with an evenly distributed starting water level of 424 m, msl, and allowed to equilibrate during the two year span in time period I. As expected, flow gradients increased near the lake when low water lake levels were simulated. Very high flow rates into the lake were produced from these lower lake level simulations. At lake water levels higher than normal (422.8 and 423 m, msl), flow gradients decreased. Water levels farther upgradient were only slightly influenced, however, those near the lake were raised by more than 50 cm.

Overall, varying the wetland water level influenced the flow system more than when lake levels were varied. Lake levels were seen to influence head gradients near the lake. It is apparent that the water level in the wetland is more influential to the majority of the site groundwater system. When wetland water levels are high, local perturbations are removed from the system.

<u>*Climatic Factors*</u>

Increments of evenly and unevenly distributed constant recharge rates were tested

(Table V.6). The results of infiltration rate and field survey maps were used to create an unevenly distributed recharge map (Figure V.9). Ranges of infiltration were assigned a weighting factor, which was applied to the average recharge rate calculated from water level rises in water table wells. Zones were assigned a value based on relative infiltration rates and the amount of area covered by the zone. The resulting unevenly distributed recharge ranging from 6.96×10^{-5} to 6.96×10^{-4} m/d (1 to 10 in/yr) were modeled to simulate the effects of actual precipitation and infiltration rate variations.

For both evenly and unevenly distributed recharge rates up to 2.78×10^{-4} m/d (4 in/yr), produced reasonable hydraulic heads. Mounding in the northern portion of the site and a small depression in the water table near the wetland is formed with recharge rates ranging from 3.48×10^{-4} to 6.96×10^{-4} m/d (5 to 10 in/yr). For recharge rates greater than 6.96×10^{-4} m/d (5 in/yr), up to 20 cm higher hydraulic heads occurs near the lake than further upgradient near the spray zone. Overall, results of the unevenly distributed recharge rates produced slightly better results than the simulations with the equivalent evenly distributed recharge rates, indicating the importance of focused recharge on the local flow systems.

The influence of *Etp* was tested with two different variable grids and evenly distributed rates. Th first variable grid of *Etp* (Figure V.10) was based on types of vegetation at the site. Another test of unevenly distributed *Etp* rates was run with areas north of the railroad having an *Etp* or 1.39×10^{-3} m/d (20 in/yr) and areas south of the railroad having an *Etp* of 8.35×10^{-4} m/d (12 in/yr). This design was chosen because more infiltration occurs upgradient than downgradient of where the pipeline break occurred. For this particular run, water surfaces had an *Etp* of 2.09×10^{-3} (30 in/yr). Unevenly distributed rates, based on vegetation, were seen to produce a closer fit to field hydraulic heads than the other tested *Etp* conditions. However, the difference was not significant. Evenly distributed *Etp* rates of 1.04×10^{-3} and 1.74×10^{-3} m/d (15 and 25 in/yr) were also tested. As expected, low evenly distributed *Etp* rates formed a large amount of flow out of the model and higher water levels throughout the site. Overall, flow patterns were only influenced to a small degree in the area just downgradient of the wetland.

Table V.6 Recharge and evapotranspiration rates used in time-constant simulations

VARIABLE RECHARGE VALUES*3

Average Recharge		Recharge Zones (m/d)						
in/yr	m/d	1	2	3	4	5	6	
Modeled Values								
2	1.39E-04	1.27E-04	5.34E-05	8.18E-05	0	5.34E-04	1.21E-03	
Tested Values								Comments*4
1	6.96E-05	6.96E-05	2.67E-05	4.09E-05	0	2.67E-04	6.04E-04	14 - 17 cm U
3	2.09E-04	1.91E-04	8.02E-05	1.23E-04	0	8.02E-04	1.81E-03	12 -62 cm D
4	2.78E-04	2.54E-04	1.07E-04	1.64E-04	0	1.07E-03	2.42E-03	
5	3.48E-04	3.18E-04	1.34E-04	2.04E-04	0	1.34E-03	3.02E-03	
6	4.18E-04	3.82E-04	1.60E-04	2.45E-04	0	1.60E-03	3.63E-03	
7	4.78E-04	4.45E-04	1.87E-04	2.86E-04	0	1.87E-03	4.23E-03	
8	5.57E-04	5.09E-04	2.14E-04	3.27E-04	0	2.14E-03	4.83E-03	
9	6.26E-04	5.72E-04	2.40E-04	3.68E-04	0	2.40E-03	5.44E-03	
10	6.96E-04	6.36E-04	2.67E-04	4.09E-04	0	2.67E-03	6.04E-03	

CONSTANT RECHARGE VALUES*2

Tested Values

Average Recharge		Comments
in/yr	m/d	
1	6.96E-05	15 - 62 cm U
3	2.09E-04	13 - 72 cm D
4	2.78E-04	
5	3.48E-04	High rates greatly affect flowpaatterns and head values.
6	4.18E-04	The lake area is more influenced.
7	4.78E-04	
8	5.57E-04	
9	6.26E-04	
10	6.96E-04	

VARIABLE EVAPOTRANSPIRATION VALUES*1,*3

I) Variable by vegetation

	Evapotranspiration, Et		Comments
Vegetation	in/yr	m/d	
Bare soil	11.28	7.85E-04	Average 20 cm U and D
Grass	14.6	1.02E-03	
Pine trees	19.4	1.35E-03	
Aspen trees	21	1.46E-03	
Water	25	1.74E-03	

II) Variable by location

	Evapotranspiration, Et		Comments
Location	in/yr	m/d	
South	12	8.35E-04	Average 20 cm U and D
North	20	1.39E-03	
Water	30	2.09E-03	

CONSTANT EVAPOTRANSPIRATION VALUES*1,*2

Tested Values

Average Etp		Comments
in/yr	m/d	
15	1.04E-03	Average 20 cm U and D
25	1.74E-03	

*1 Extinction depth is 3 m for all simulations

*2 Areally, evenly distributed values

*3 Areally weighted values

*4 Average head difference from field data. U=upgradient location, node (7,21) and D=downgradient location, node (17,6)

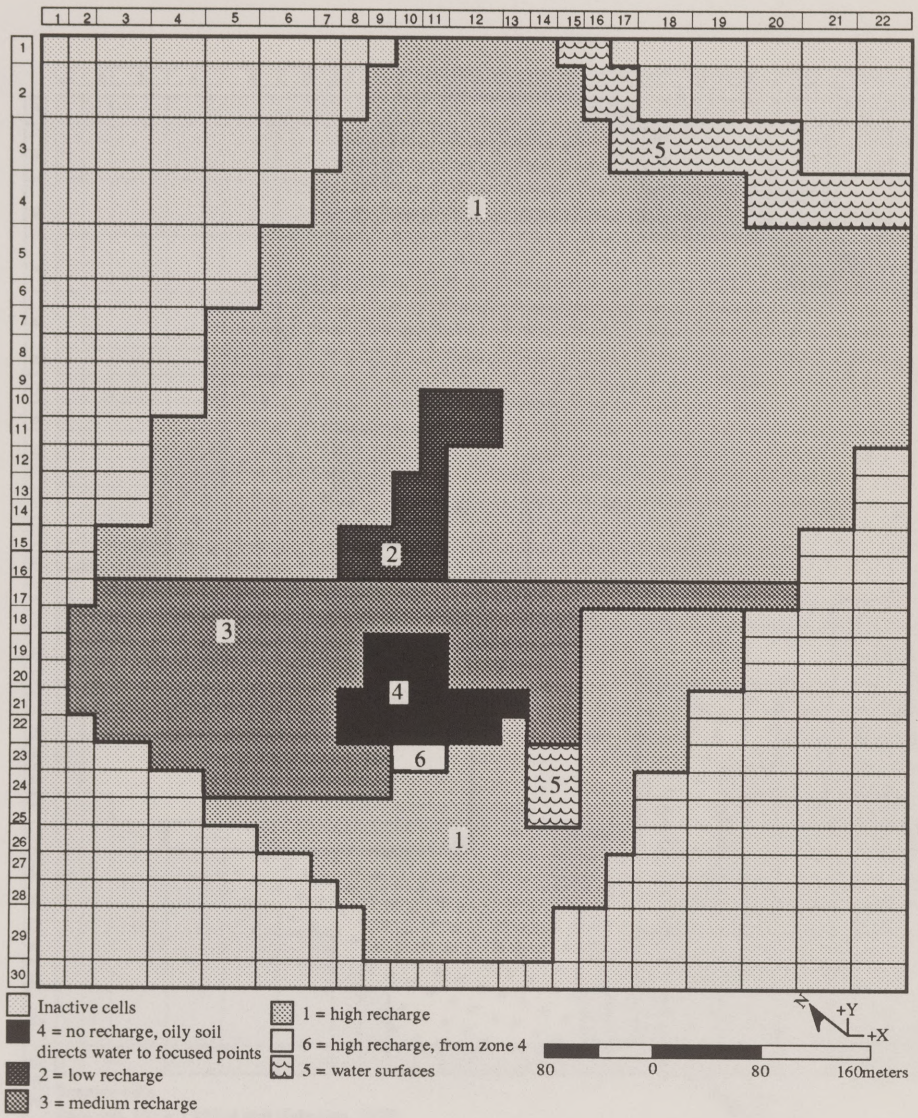


Figure V.9 Zones of varying recharge

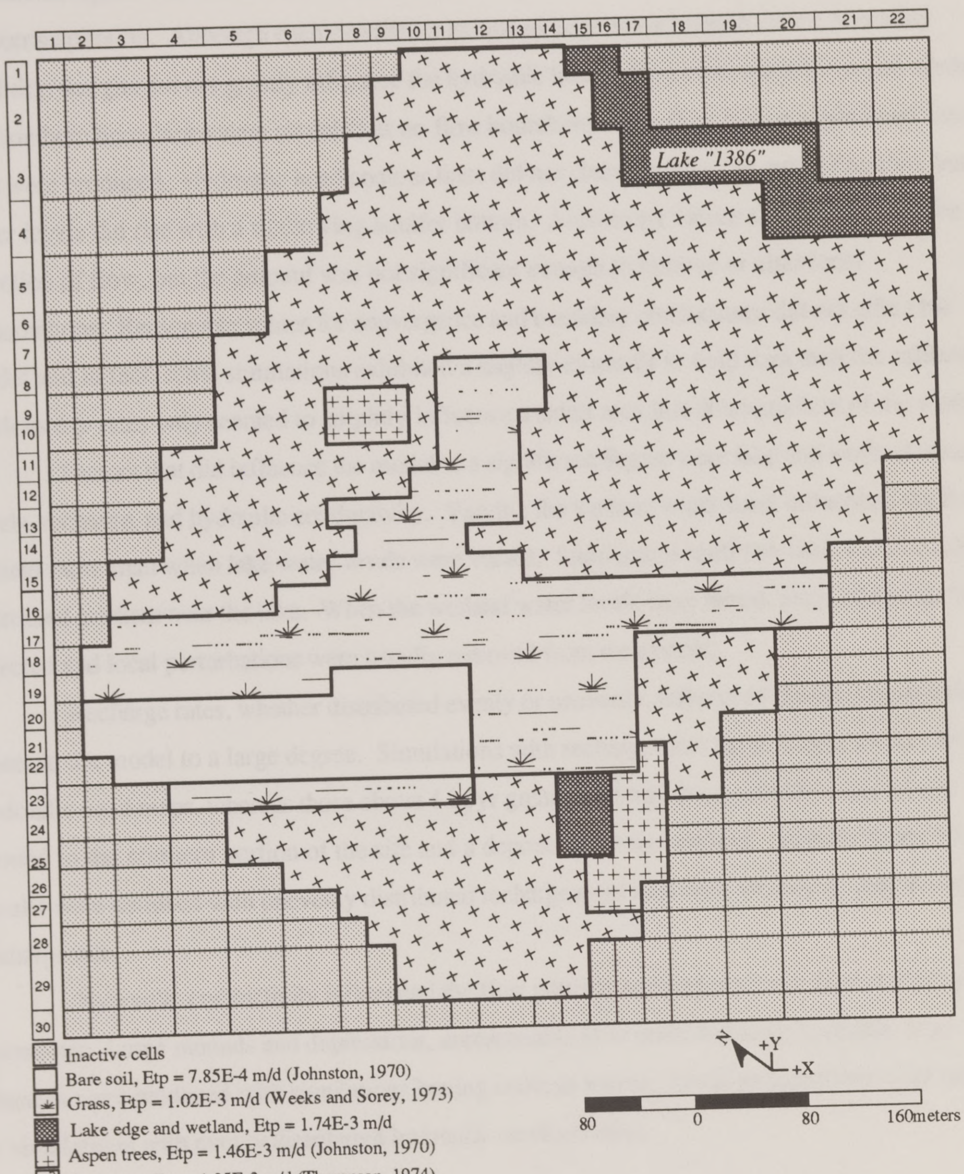


Figure V.10 Map of evapotranspiration zones based on vegetation type.

Summary of Sensitivity Analysis

The factors that did not influence the model to a significant degree are the boundary conditions, aquifer bottom elevation and configuration, anisotropy, conductance, and evapotranspiration. Although each simulation exhibited large mass balance errors, boundary condition designs did not greatly influence the hydraulic heads. However, when the entire northern and southern boundaries were modeled as no-flow boundaries, high flow rates and gradients into the lake were produced. Hydraulic head contour lines did not change with a flat aquifer bottom, but water levels did rise with a shallowing aquifer bottom. Anisotropy values slightly effected the direction of flow, but the amount was not significant enough to remove or alter local perturbations. Reasonable values for convergence and boundary conductance did not affect the model and in fact, some simulations exhibited a slightly closer fit to field data than the calibration. Various *Etp* rates only seemed to slightly influence a small area just downgradient of the wetland.

Factors that did influence the model to a significant degree were lake and wetland water levels, recharge, and hydraulic conductivity. Varying the wetland water level influenced the flow system more than when lake water levels were varied. Simulations with low lake water levels increased gradient near the lake. When the wetland water levels were raised, more of the site was affected and local perturbations were usually removed from the system.

Recharge rates, whether distributed evenly or unevenly, influenced the amount of available water in the model to a large degree. Simulations with recharge rates up to 4 in/yr closely fit field hydraulic head maps, whereas those above 4 in/yr greatly affected the results showing a large mound in the northern portion of the site and a depression in the wetland. Slightly better fitting results were obtained with unevenly distributed recharge rates than with the evenly distributed recharge rate.

Hydraulic conductivity influenced the flow patterns and budgets more than any other parameter. Large mounds and depressions, unreasonable flow rates, and large hydraulic head changes were produced with simulations having extreme values. Local perturbations were removed in simulations with evenly distributed hydraulic conductivities.

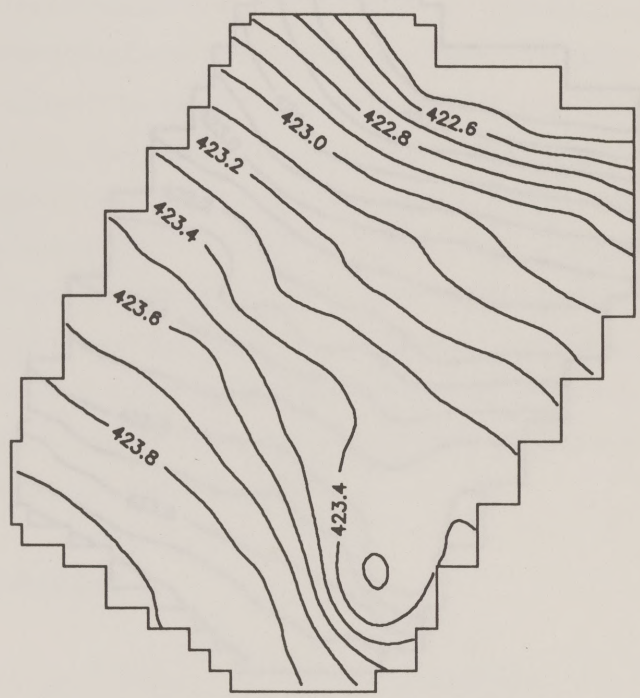
Time-Varying Parameter Testing

The Bemidji site is greatly effected by seasonal and annual fluctuations. Therefore, the previous simulation with constant rates does not simulate actual conditions. A series of steady-state models, representing the changing seasons, is used to simulate these effects. Climate may create local perturbations in the water table when the water table is near the ground surface during extreme conditions. This next phase attempts to recreate these influences by introducing a changing hydrologic budget.

The final parameters to be tested with changing climatic influences are almost exactly the ones first chosen parameters prior to the sensitivity analysis (Table V.2). The exceptions are an unevenly distributed recharge map (averaging 2 in/yr), a convergence criterion of 0.0001 m, and the addition of general head boundary cells in the wetland. The resulting water table map (Figure V.11) shows the closest fit to field data (Figure V.12). Simulated heads were mostly within 10 cm of field data. However, in the wetland and northern areas, head differences up to 30 cm were simulated. The resulting flow rates are shown in Table V.7. A look at the system under more realistic conditions is simulated with seasonal variations in recharge and *Etp*. With the exception of changing recharge and evapotranspiration rates, all other parameters remain the same as the calibrated and tested simulations.

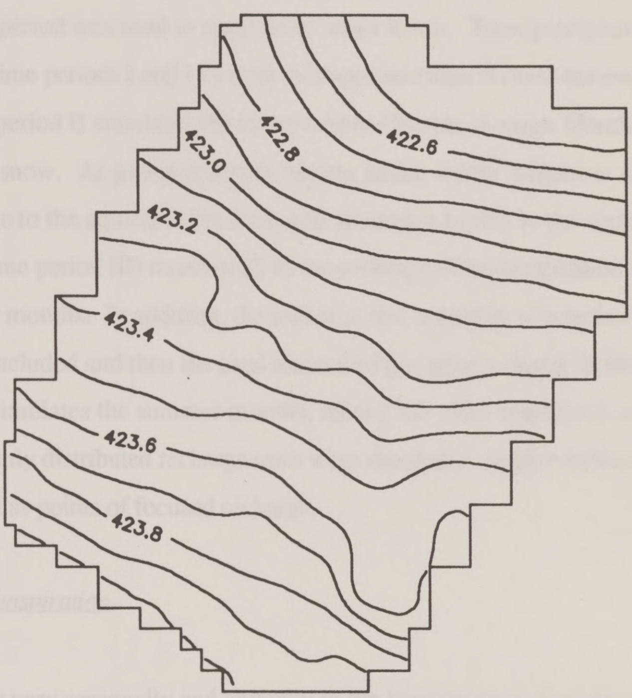
Table V.7 Resulting Rates (m^3/d) after Sensitivity Analysis

IN:		OUT:	
STORAGE =	0.	STORAGE =	0.
CONSTANT HEAD =	0.	CONSTANT HEAD =	18.863
RECHARGE =	31.495	RECHARGE =	0.
ET =	0.	ET =	12.636
HEAD DEP BOUNDS =	39.789	HEAD DEP BOUNDS =	39.786
TOTAL IN =	71.284	TOTAL IN =	71.286
IN - OUT =	-0.199455E-02	PERCENT DISCREPANCY =	0.00



1 inch = 187 meters

Figure V.11 Simulated heads following sensitivity analysis. Contour interval is 0.1 m. Water elevation is in meters above mean sea level.



1 inch = 187 meters

Figure V.12 Starting hydraulic head. Contour interval is 0.1 m. Water table elevation is in meters above mean sea level.

Recharge

During this study, unusually dry weather resulted in a declining water table. The deeper water table was less effected by topography and local recharge variations than during normal conditions. Also, during the rain periods in the summer months *Etp* is high as well and precipitation is either not expected to recharge the aquifer or only one half of the potential recharge is expected to reach the aquifer (Brassington, 1988). Snowmelt becomes the most important recharge event.

Table V.8 lists the values for recharge that were initially chosen for this simulation. Time period I lasts 155 days and represents the summer season when recharge and *Etp* rates are at a maximum. This period was used to equilibrate water levels. Total precipitation occurring in the summer season (time periods I and IV) were averaged and then divided out evenly over the entire 155 days. Time period II simulates the months from October through March, when precipitation is in the form of snow. As precipitation occurring in the winter months is most likely to be snowfall, recharge to the aquifer is delayed until snowmelt begins in the spring.

April (time period III) receives all of the recharge from precipitation events that occurred during the winter months. In addition, the recharge that normally occurs in April, due to precipitation, is included and then the total amount of potential recharge is entered into the aquifer. Time period IV simulates the summer months, having the same conditions as time period I. Evenly and unevenly distributed recharge rates were simulated. Higher recharge rates were assigned to areas identified as points of focused recharge.

Evapotranspiration

Etp rates vary seasonally and annually in the Bemidji area. Extreme temperatures occur both in the summer and winter months. During the short time of this study, unusually high temperatures were recorded in the summer months, along with lower precipitation rates. A deeper water table is effected less by evapotranspiration than during normal conditions. The small amount of water infiltrating the ground surface probably does not reach the water table when subjected to high evapotranspiration rates.

Table V.8 lists the values for *Etp* used to simulate the changing hydraulic heads. Time period I, simulating the summer season, is assigned a high *Etp* rate of 3.34×10^{-3} m/d (4 in/mo).

Table V.8 Recharge and evapotranspiration rates used in time-varying simulations

Time Period	Time Steps	Simulated Month	Typical Field Water Level Behavior	*Etp* (m/d)	Seasonal rates when the estimated average recharge is: (in/yr)	1	2	4
I	1	155 day equilibration	-	3.39E-03	(m/d)	1.10E-04	2.19E-04	4.38E-04
II	1	October	falling	0	(m/d)	0	0	0
	2	November	falling					
	3	December	falling					
	4	January	falling					
	5	February	falling					
	6	March	falling					
III	1	April	rising	7.45E-04	(m/d)	2.81E-04	5.62E-04	1.12E-03
IV	1	May	rising	3.39E-03	(m/d)	1.10E-04	2.19E-04	4.38E-04
	2	June	rising					
	3	July	peak					
	4	August	falling					
	5	September	falling					
MODEL TOTAL			(in/yr)	20.88				

Significantly higher values of *Etp* occur during the summer months than in the winter months. Winter precipitation is stored above ground, where snow may be subjected to evaporative losses. As this amount is very low, the *Etp* rate for time period II was assigned a zero amount. Time period III, simulating the month of April, is assigned a low *Etp* rate of $7.35x10^{-4}$ m/d (0.88 in/mo). *Etp* in the fourth time period is assigned the same conditions as in time period I.

Model Determination

<u>Trial runs</u>

The calibrated model, after completion of the sensitivity analysis, was run at the various evenly distributed recharge rates shown in Table V.8. Recharge rates of $6.96x10^{-5}$, $1.39x10^{-4}$, and $2.78x10^{-4}$ m/d (1, 2, and 4 in/yr) were tested because these values were seen to produce reasonable hydraulic heads in the sensitivity analysis. The results indicated that although the model was calibrated under constant recharge and *Etp* for a particular time, simulations were unable to reproduce the field data within the range tested. All simulations showed depressions in the wetland and large water table mounds in the northwest after the large snowmelt input of recharge in April (time period III).

Although time period I (recharge rate of $6.96x10^{-5}$ m/d (1 in/yr)) modeled reasonable flow rates and volumes, hydraulic heads did not change much. As expected, water levels increased from March to April. The wetland did not form a mound, as earlier projected, but continued to form a deeper depression at higher elevations. This could be due to the evenly distributed recharge and evapotranspiration. Due to the large amount of *Etp*, water levels slightly decreased. The final hydraulic head maps in August and September were comparable with field data.

A recharge rate of $1.39x10^{-4}$ m/d (2 in/yr) produced similar results, but showed a larger flow gradient. Flow rates increased and flow patterns in the summer months did not fit field data as well as in the previous simulation. Throughout the entire simulation, the wetland showed a depression, which changed in size but not elevation. The last simulation, having a recharge rate of $2.78x10^{-4}$ m/d (4 in/yr), exhibited unreasonable flow patterns, allowing too much flow out of the site in every direction.

An unevenly distributed recharge map was then simulated at $1.39x10^{-4}$ m/d (2 in/yr). Hydraulic head contour lines were slightly better, however, the snowmelt recharge still caused a large amount of mounding in the northwestern and northern portion of the site. An increased recharge rate at points of focused recharge only served to increase water levels in the depression, not form a mound. This indicated that the model may have other parameters in need of reevaluation.

As the model could not be calibrated in previous simulations, the following tests were conducted to determine if any other constant parameters had been incorrectly chosen. Hydraulic conductivities in the wetland, kettle, and lake area were tested at higher and lower rates. Forming a water table mound in the wetland seemed plausible if at that point hydraulic conductivities are low (0.3 and 0.864 m/d (3.47×10^{-6} and 10^{-5} m/s) and recharge rates are high. The supply of water would outweigh the movement of water through the silt and possibly form a mound. However, simulations showed that low hydraulic conductivities only increased the depression depth and during snowmelt recharge created a large water table mound in the northwestern portion of the site. High hydraulic conductivities in the wetland (10 m/d (10^{-4} m/s) did not improve the simulation, except for in the winter time period, which showed a small depression in the wetland.

A uniform hydraulic cónductivity value of 2.16 m/d (2.5×10^{-5} m/s) removed all previously modeled local anomalies and did not create the small perturbations in the kettle. As a result of assigned general head boundaries in the wetland area, a depression in the wetland was present. Spring (February) simulations closely fit the field data, forming a flow-through pattern in the wetland. However, the snowmelt recharge created too large of a mound in the northwestern portion of the site.

As the wetland cells had been assigned conductance values, the following was simulated to determine if these values had been incorrectly chosen. Simulations indicated that with a conductance of 0.1, a depression did not form in the wetland. Flow through conditions occurred at all times and water levels were at an elevation that fit the field data more closely than the previous tests. Flow rates were reasonable, however, water levels were dramatically increased after snowmelt and again, a large water table mound formed in the northwestern portion of the site.

Final simulation

Several attempts at calibrating the time-varying version of the final time-constant simulation resulted in a reevaluation of model conditions and parameters. Although the model had been verified after the initial calibration and sensitivity analysis, those model conditions were unable to produce a closely fitting time-varying simulation. In summary, large water table mounds consistently formed in the northwestern portion of the site and depressions formed in the wetland area. These features would unrealistically increase in size with decreasing hydraulic conductivity and increasing recharge rate. Because the model was calibrated for a time period, it seems unable to be verified in a time-varying simulation under the chosen time-varying parameters. The following is a description of the parameters and model conditions which were able to produce a simulation that closely fit seasonal groundwater flow response seen in field data.

The model parameters are the same as those finalized after the sensitivity analysis, with the exception of hydraulic conductivity, distribution, and the assigned time period order. The largest modification of input parameters was an evenly distributed hydraulic conductivity. Although this design removed smaller local perturbations seen at the kettle area, this hydraulic conductivity rate (2.16 m/d (2.5×10^{-5} m/s)) produced the closest fit to the desired field patterns. The initial warm-up period (time period I in the final version after the sensitivity analysis) was removed because the starting head values were actually field conditions from the August-September time period. The new designated time periods are shown in Table V.9.

Evapotranspiration rates were applied evenly over the model and were constant throughout each individual time period (Table V.9). The uneven recharge rate distribution was slightly modified to have pronounced recharge in the lower lying areas at the site, such as the kettle, wetland, and lake shoreline. The areally averaged recharge rate for each time period is displayed in Table V.9. A total of 4.3 cm (1.7 in) recharge occurs during the entire simulation (365 days).

Table V.9 Time-Varying Conditions

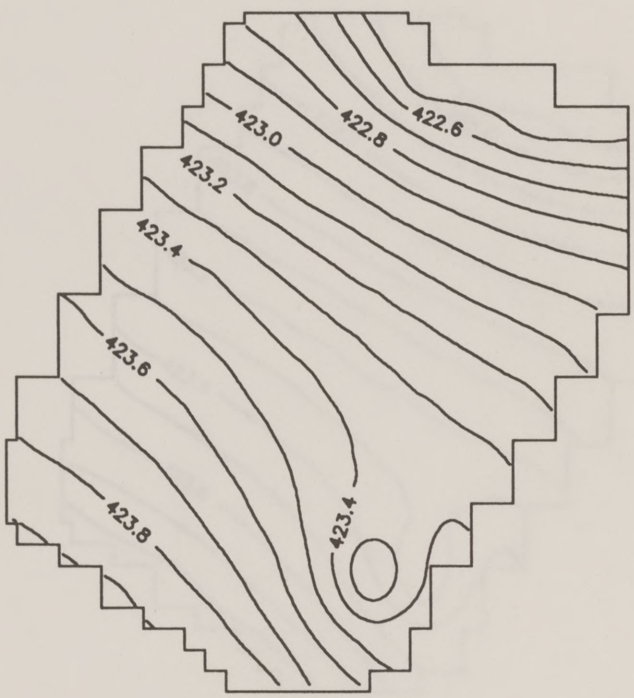
Time Period	Time Steps	Simulated Month	Water level Response	*Etp*	Modeled *Etp* rate	Recharge	Modeled Average Recharge rate
I	1	October	falling	little	0	rain	0
	2	November	falling	no	0	snow	0
	3	December	falling	no	0	snow	0
	4	January	falling	no	0	snow	0
	5	February	falling	no	0	snow	0
	6	March	falling	no	0	snow	0
II	1	April	rising	yes	7.45E-4m/d	snowmelt	2.68E-4m/d
II	1	May	rising	yes	2.29E-3m/d	rain	1.89E-4m/d
	2	June	rising	yes	2.29E-3m/d	rain	1.89E-4m/d
	3	July	peak	yes	2.29E-3m/d	rain	1.89E-4m/d
	4	August	falling	yes	2.29E-3m/d	rain	1.89E-4m/d
	5	September	falling	yes	2.29E-3m/d	rain	1.89E-4m/d

Hydraulic heads are displayed in Figures V.13, V.14, and V. 15 for the simulated months of August, February, and April, respectively, and the associated flow budgets are displayed in Table V.10. The water table in August resembles field data and has a slight depression in the wetland area. Flow-through conditions may be present. *Etp* losses at this time are three times higher than in the coming months. The February water table map indicates flow-through conditions in the wetland. The water table is deep and is not influenced by local topography. In the month of April, the aquifer is recharged from snowmelt and precipitation events. Approximately 0.8 cm (0.32 in) of recharge occurs during this time. This amount is much lower than the potential recharge calculated from precipitation data (3.8 cm (1.5 in)). Twenty-three percent of the annual recharge was modeled to occur during April, the rest occurs in the summer and early autumn months (time period III). In all time periods, the flow gradient closely fits field data and increases towards the lake. Groundwater velocities, calculated from simulated hydraulic heads, ranged from 1.4×10^{-3} to 8.9×10^{-3} m/d.

Discussion

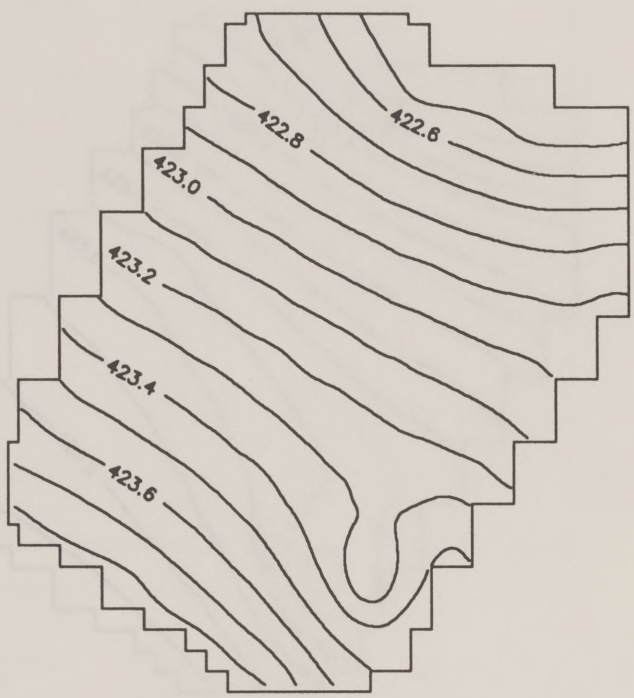
The main objective of the modeling was to calibrate a hydraulic head simulation of the field observations and to infer groundwater flow patterns. This goal was obtained, however, the model remains to be tested as a predictive tool for determining future conditions. An understanding of the recharge-discharge relation aided in calibrating the rates with observed data. The sensitivity analysis evaluated the importance of different processes such as recharge, evapotranspiration, and boundary conditions and indicated which model and aquifer parameters control the groundwater system. Stratigraphy, permeability of surface sediments, and the interaction between topography and climatic conditions are the major controls. The steady-state model could not be calibrated while subjected to typical climatic conditions and had to be adjusted before a verified version was completed. The groundwater velocities are approximately one order of magnitude more than those determined by others (Table IV.1). This difference may be a result of the higher hydraulic conductivities earlier estimated and measured from deeper within the aquifer.

The heterogeneity of surficial sediments and aquifer materials are controls on hydrogeologic parameters. The hydraulic conductivity rate and distribution influenced the model most. Evenly and unevenly distributed hydraulic conductivities, ranging from 1.5 to 2.16 m/d, modeled water levels and flow rates that closely fit field data. The final version of the



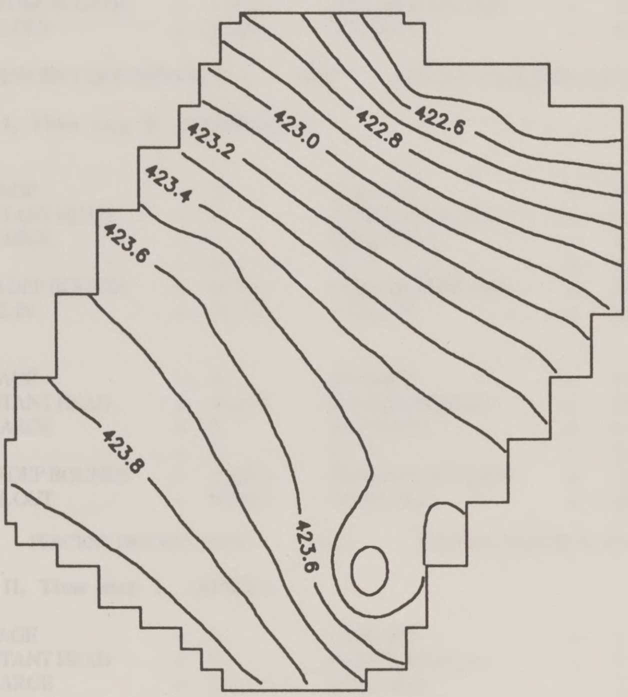
1 inch = 187 meters

Figure V.13 Simulated time–varying head, time period 3, time step 4 (August). Contour interval is 0.1 m. Water table elevation is in meters above mean sea level.



1 inch = 187 meters

Figure V.14 Simulated time–varying head, time period 1, time step 5 (February). Contour interval is 0.1 m. Water table elevation is in meters above mean sea level.



1 inch = 187 meters

Figure V.15 Simulated time-varying head, time period 2, time step 1 (April). Contour interval is 0.1 m. Water table elevation is in meters above mean sea level.

Table V.10 Resulting Flow Budget from Time--Varying Simulation

Time period III, Time step 4 (AUGUST)

	CUMULATIVE VOLUMES m^3			RATES FOR THIS TIME STEP m^3/d		
IN						
	STORAGE	=	0.	STORAGE	=	0.
	CONSTANT HEAD	=	0.	CONSTANT HEAD	=	0.
	RECHARGE	=	8617.5	RECHARGE	=	51.654.
	ET	=	0.	ET	=	0.
	HEAD DEP BOUNDS	=	17032.	HEAD DEP BOUNDS	=	43.571
	TOTAL IN	=	25649.	TOTAL IN	=	95.226
OUT						
	STORAGE	=	0.	STORAGE	=	0.
	CONSTANT HEAD	=	11985	CONSTANT HEAD	=	40.744
	RECHARGE	=	0	RECHARGE	=	0.
	ET	=	2542.4	ET	=	18.896
	HEAD DEP BOUNDS	=	11123.	HEAD DEP BOUNDS	=	35.589
	TOTAL OUT	=	25650	TOTAL OUT	=	95.23
	PERCENT DISCREPANCY	=	0.00	PERCENT DISCREPANCY	=	0.00

Time period I, Time step 5 (FEBRUARY)

IN						
	STORAGE	=	0.	STORAGE	=	0.
	CONSTANT HEAD	=	0.	CONSTANT HEAD	=	0.
	RECHARGE	=	0.	RECHARGE	=	0.
	ET	=	0.	ET	=	0.
	HEAD DEP BOUNDS	=	9070.1	HEAD DEP BOUNDS	=	60.467
	TOTAL IN	=	9070.1	TOTAL IN	=	60.467
OUT						
	STORAGE	=	0.	STORAGE	=	0.
	CONSTANT HEAD	=	4601.8	CONSTANT HEAD	=	30.679
	RECHARGE	=	0.	RECHARGE	=	0.
	ET	=	0.	ET	=	0.
	HEAD DEP BOUNDS	=	4468.5	HEAD DEP BOUNDS	=	29.790
	TOTAL OUT	=	9070.3	TOTAL OUT	=	60.469
	PERCENT DISCREPANCY	=	0.00	PERCENT DISCREPANCY	=	0.00

Time period II, Time step 1 (APRIL)

IN						
	STORAGE	=	0.	STORAGE	=	0.
	CONSTANT HEAD	=	0.	CONSTANT HEAD	=	0.
	RECHARGE	=	2212.3	RECHARGE	=	73.744
	ET	=	0.	ET	=	0.
	HEAD DEP BOUNDS	=	11629.	HEAD DEP BOUNDS	=	24.837
	TOTAL IN	=	13842.	TOTAL IN	=	98.581
OUT						
	STORAGE	=	0.	STORAGE	=	0.
	CONSTANT HEAD	=	6932.2	CONSTANT HEAD	=	0.
	RECHARGE	=	0.	RECHARGE	=	47.001
	ET	=	199.25	ET	=	0.
	HEAD DEP BOUNDS	=	6710.1	HEAD DEP BOUNDS	=	44.930
	TOTAL OUT	=	13842.	TOTAL OUT	=	98.572
	PERCENT DISCREPANCY	=	0.00	PERCENT DISCREPANCY	=	0.01

time-varying model was calibrated with an evenly distributed rate of 2.16 m/d. Although simplistic, the modeled flow patterns and gradients closely fit field data.

Vegetation and soil characteristics influence the amount of recharge and its distribution. Simulations with recharge rates higher than 2.78×10^{-4} m/d (4 in/yr) were seen to produce a large water table mound in the northwest portion of the site and a large depression in the wetland. The water table mound was often large enough to direct flow out of the originally upgradient flow boundary in the southwest. Simulations of evenly and unevenly distributed recharge rates, whether applied as time-constant or time-varying, showed the same response. The model was calibrated with an annual recharge rate of 1.18×10^{-4} m/d (1.7 in/yr), which was unevenly distributed across the site. Approximately 1.35 cm (0.53 cm) of evapotranspiration occurred over the simulated year, with greater than 93% applied during the summer months.

The time-varying model simulates a large amount of water discharging into the wetland from all directions. Flow gradient (0.0026) throughout the rest of the site is typical of field conditions (0.0027) showing increasing gradient towards the lake. High water levels are present in the summer (August). Approximately 10-20 cm of hydraulic head loss occurs by February when the flow gradient (0.0024) is more evenly spaced over the site than in the previous season. Flow is straight towards the lake. Runs with evenly distributed hydraulic conductivity rates did not show any observed small field perturbations near the kettle. Snowmelt recharge begins in April, increasing water levels about 10 to 30 cm. As recharge occurs, gradient is increased near the lake. Overall, water levels are most affected near the wetland and *lake "1386"*, areas that respond quickly to changing climatic conditions.

VI. CONCLUSIONS

Summary

The groundwater flow system at the Bemidji research site is strongly influenced by the topography, glacial stratigraphy, characteristics of the surficial sediments, and climatic conditions. Although landforms (kettles, lakes, and wetlands) are of low relief, they significantly affect the hydrologic system. The heterogeneity of the aquifer material and surficial sediments control the hydrogeologic parameters of the aquifer. The factors creating seasonal changes in the hydrologic system are recharge and evapotranspiration.

A wide range of material composition, size, sorting, and vertical anisotropy exists within the aquifer. Horizontal hydraulic conductivities dominate the hydrologic system. However, some locations are characterized by either higher vertical hydraulic conductivities or by vertical hydraulic conductivities of equal magnitude. Intrinsic permeability and hydraulic conductivity are highly variable and range over 6 orders of magnitude. Although glacial drift aquifers are typically characterized as homogeneous, it is clear that on the scale and the range and distribution of hydrogeologic parameters at the site, the local aquifer is heterogeneous.

The stratigraphy controls the local groundwater flow system because several finer-grained discontinuous layers form hydrologic discontinuities. Groundwater flow is fast through large-grained sediments in the outwash, but within the outwash sediments the fine-grained layers slow groundwater and create local flow heterogeneities imprinted on the regional groundwater system. A fine-grained silt layer near or below the water table may influence the vertical flow field in areas where seasonal reversals were observed.

In the *spray zone*, depressions and mounds occur in the water table and probably result from the interplay of the water table and the fine-grained silt layer. Recharge to the aquifer at the silt layer mounds water on top of the unit. Because the *spray zone* has a semi-impermeable "membrane" of oil-coated sediments, recharge in this area is commonly small. The response of the water table when near the silt layer is controlled by the hydraulic conductivity of the silt layer.

Surface conditions, such as soil and vegetation type and abundance, amount of oil on sediments, and hillslope topography, largely affect the surficial processes occurring at the site. Infiltration rate and surface water flow have a significant effect on the groundwater system. Variabilities in these controls were shown to result not only from the added influence of oil on grain surfaces in the *spray zone*, but from natural sediment and vegetation differences and micromorphology of the land as well. During snowmelt and rainfall events, surface water flows over the impermeable soils to locally focused points of recharge. Depressions, such as the kettle, wetland and *lake "1386"*, receive runoff from surrounding areas, as do the low-lying areas surrounding the *spray zone*, which receive all the precipitation falling onto and running off of oil-covered sediments. Infiltration rate characteristics change as sediment is redistributed by erosion. Currently eroding areas in the *spray zone*, areas characterized by low infiltration capacity and high oil content, may increase the infiltration rate as the semi-permeable "membrane" is weathered and eroded. Areas formerly characterized by clean sands and high infiltration rates may become covered by oily sediments that eventually lower the infiltration rate.

A small recharge-discharge system is present within the kettle. During snowmelt, overland flow transports all of the surface water into the kettle and enters the unsaturated zone at the lowest point in the kettle. At this location, recharge forms a groundwater mound. During warmer periods, when rainfall is high, recharge is more evenly distributed, allowing for occasional downward flow at other areas in the kettle. "Clean" recharge water moves down into the aquifer, mixes with water originating deeper in the aquifer, and forms a diluted water found at shallower depths in the western portion of the kettle.

Variations in water table elevation were closely correlated with seasonal fluctuations in rainfall, temperature, and evapotranspiration, especially in shallow areas, such as the kettle and wetland. Focused evaporation can occur where the water table is close to the ground surface. Water levels in these areas respond quickly to local climatic changes. In times of high recharge, groundwater flows in a regional direction with two areas of focused recharge located in the kettle and the wetland. Mounding occurs in the wetland and kettle area throughout most of the year. Groundwater then flows out of these areas and converges with the regional flow direction. Over the last 5 years, the dry seasons have lowered the water table, probably decreasing the effect of local topography. Although fluctuations of up to 0.5 m were measured in the flow field at the wetland, larger fluctuations should be expected under normal annual climatic conditions.

MODFLOW was used to model the groundwater response to local climatic changes. Significant factors were lake and wetland water levels, and rates and distribution of recharge and hydraulic conductivity. The factors that did not influence the model to a significant degree are the boundary conditions, aquifer bottom elevation and configuration, horizontal anisotropy, conductance, and evapotranspiration.Overall, the model was most influenced by the magnitude and spatial distribution of hydraulic conductivity. Although the final simulation of a changing hydrologic budget was simplistic, the modeled flow patterns and gradients closely fit the field data. The results supported an earlier suggestion that water levels are most affected near the wetland, kettle, and *lake "1386"*.

Recommendations for future studies

During previous studies, only a few chosen wells in the vicinity of the oil lens have been used for water level measurements. These limited data records do not give insight into the entire site. Water levels in all wells should be taken on a weekly basis in order to determine short range fluctuations in the flow field, particularly in the vicinity of the oil lens, contaminant plume, kettle, and wetland. Correlations of weekly recorded precipitation and water level changes can be used to determine the response time of water levels to storm events. Water levels in the lake and the staff gages in the wetlands and nearby bodies of water should be measured more often to determine if there is simultaneous water level change in this area or if local heterogeneities in the geologic system determine the local response. Strategically important wells should be selected for continuous water level recording.

Unsaturated zone studies, such as soil moisture profiles, are a next step to understanding the spatial and temporal variations in the spatial distribution of infiltration rates at the site. Seepage rates into *lake "1386"* have not been measured accurately and should be determined. A study of the hydraulic conductivities determined from slug tests would be a worthy addition to the site database of the distribution of aquifer parameters at the water table.

Stratigraphic features and processes are well constrained, however, the work is not complete, nor has it been published in a journal outside of the U. S. Geological Survey . As the entire database collected by other scientists is too large for this thesis to include, only the core descriptions from the cores collected for this study were included. A more complete collection of well logs is needed.

The combination of new water level records in the lake area and future modeling of the groundwater system at the site should give more insight to the characteristics and response of the contaminant plume as it migrates towards *lake "1386"*. Modeling of the groundwater system in a locally focused area of recharge will be useful to researchers studying transport of contaminants in similar geologic conditions. Characterization of the site can be used to develop a predictive model at sites of contamination in similar geologic sediments and geomorphological features.
The prediction of flow patterns at the Bemidji site can be applied to similar cases of subsurface contamination in areas of having a similar combination of glacial drift sediments and

hummocky terrains.

VII. APPENDICES

Appendix A1 Well Database

Explanation

						OPERATIONAL INFORMATION						ORIGINAL DATA						
Well Number	LOCATION *a		Well Description Codes			Measuring Point (MP) Elevation	Stick Up	Land Surface Elevation	Screen Top (ST) Elevation	Screen Bottom Elevation	Well Bottom Elevation	Measuring Point Elevation	Stick Up w/units	Depth to ST from MP	Screen length	Tailpipe length	Total depth from MP w/units	Elevation of Total Depth
	X	Y				*e	*f	*g	*h	*i	*j	*k	*l	*m	*n	*o	*p	*q
	(m)	(m)	*b	*c	*d	(m)	(m)	(m)	(m)	(m)	(m)	(ft)		(ft)	(ft)	(ft)		(ft)

*a is the location of the well in an XY coordinate system, (+)X is oriented N52.3°E
*b is the type of well. p is a production well, o is an oil well, g is a gas well, w ia a water well, and x is a stratigraphy collection location.
*c is the construction material of the well. b is black steel, g is galvanized steel, p is polyvinyl chloride, s is stainless steel, and x is a stratigraphy collection location.
*d is another classification of the wells. r is a regional water table well, w is a local water table well, and x is a stratigraphy collection location.
*e is the elevation of the top of the well. Slanted wells have MP at northern side.
*f is the height of the well above the land surface.
*g is the elevation of the land surface at the well location.
*h is the elevation of the screen top in the well, calculated from screen lengths, tailpipe lenghts, screen bottom, and total depth elevations.
*i is the elevation of the screen bottom, calculated from tailpipe length and total depth elevations.
*j is the elevation of the well bottom, calculated from total depth elevations.
*k is the measured elevation of the measuring point, those values followed by an "m" denote units of meters.
*l is the measured stick up with units used. Data collected by S. Bilir.
*m is the depth to screen top. M stands for measured values, DL stands for driller's logs, and P stands for data taken from P. Bennett's database.
*n is the recorded screen length.
*o is the recorded tailpipe length.
*p is the measured value of total depth with units used. Data collected by S. Bilir.
*q is the elevation of total depth. M stands for measured values, DL stands for driller' slogs, and P stands for data taken from P. Bennett's database.

Within the chart:

Blanks stand for missing data or values which can not be calculated until other data is collected, except in the *d column, where blanks mean that the location is neither a local nor regional water table well.

"x" stands for values not needed. The location is not a well, but a stratigraphy collection location.

(Benchmark located at (0,0) an at 1419.308 ft=432.605m)
Last Edited 3/26/92:SIB

Well Number		LOCATION X (m)	LOCATION Y (m)	Well Description Codes			OPERATIONAL INFORMATION Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)	
301	a	-32.81	-51.15	o	g		430.71	0.31	430.39				1413.08	1.03	ft								
301	g	-32.81	-52.88	g	s		430.44	0.32	430.11	x	x	x	1412.19	1.06	ft	x	x	x	x	x	x	x	x
302	a	-32.76	-51.96	o	g		430.47	0.22	430.25				1412.3	0.71	ft								
303	a	-48.18	-56.06	w	g	w	430.58	0.33	430.25			422.61	1412.67	1.09	ft					26.17	ft		
306	a	-31.49	-52.09	o	g		430.60	0.45	430.15				1412.74	1.48	ft								
307	a	-160.37	53.31	w	g	w/r	426.13	0.47	425.66			422.01	1398.05	1.53	ft					13.5	ft		
308	a	-58.80	38.21	w	g		427.73	0.76	426.96			421.47	1403.3	2.5	ft					20.53	ft		
309	a	107.09	-166.08	o	g		425.92	0.59	425.34				1397.39	1.92	ft								
309	b	110.72	-204.83	g	s					x	x	x				x	x	x	x	x	x	x	x
309	g	105.92	-164.13	g	s		425.57	0.76	424.82	x	x	x	1396.24	2.48	ft	x		x	x	x	x	x	x
310	a	-96.61	-238.76	w	g		433.80	0.79	433.01	423.71	422.79	422.48	1423.24	2.6	ft	33.13	M	5	1	11.32	m		
310	b	-97.49	-239.12	w	g		433.76	0.73	433.03	406.74	405.83	405.22	1423.1	2.4	ft	88.64	M	3	2	33.5	m		
310	c	-97.11	-238.13	w	g		433.94	0.91	433.03	416.41	415.50	413.75	1423.68	2.99	ft	57.5	DL	3	2.5	20.19	m	1358.5	DL
310	d	-97.89	-239.60	w	p	w	433.78	0.67	433.11	424.31		422.38	1423.17	2.2	ft	31.08	M			11.405	m		
310	e	-100.36	-241.28	w	p		433.25	0.37	432.89	423.44		421.36	1421.43	1.2	ft	32.2	M			11.89	m		
310	f	-88.10	-240.40	x	x		432.77	0.00	432.77	x	x	x	1419.86	0	ft	x	x	x	x	x	x	x	x
310	g	-100.32	-237.96	g	s		433.48	0.32	433.16	x	x	x	1422.17	1.05	ft	x	x	x	x	x	x	x	x
310	h	-99.07	-236.72	p	b		433.59	0.55	433.04	424.28			1422.53	1.8	ft	30.53	M						
311	a	14.27	46.89	w	g	w	433.42	0.81	432.61	423.30	421.75	421.22	1421.99	2.65	ft	33.21	M	5	1.75	40.04	ft	1382	M
312	a	105.00	-154.71	o	g		426.39	0.62	425.78				1398.93	2.02	ft								
313	a	112.99	-194.67	o	g		424.95	0.71	424.23				1394.19	2.345	ft								
313	b	112.12	-192.43	x	g		424.52	0.00	424.52	x	x	x	424.522m	0	ft	x	x	x	x	x	x	x	x
314	a	102.63	-142.96	o	g		426.53	0.56	425.96				1399.37	1.85	ft								
315	a	-22.54	-57.45	o	g		430.59	0.80	429.79				1412.69	2.62	ft								
317	a	-11.84	-27.77	o	g		433.01	0.68	432.33				1420.65	2.23	ft								
318	a	1.13	0.38	w	g	w	433.36	0.77	432.58	424.69	423.14	422.61	1421.77	2.54	ft	28.44	M	5	1.75	35.27	ft	1386.6	M
318	b	1.41	1.01	w	p		433.33	0.67	432.67	423.83	423.19	419.82	433.332m	2.185	ft	31.19	M	2	11.05	44.32	ft	1377	M
319	a	-20.52	-50.62	o	g		430.87	0.84	430.03				1413.61	2.75	ft								
401	a	49.33	-485.01	w	g	w/r	430.84	1.01	429.83	424.44	422.90	422.29	430.839m	3.3	ft	21	DL	5	2	8.548	m	1389	DL
402	a	-195.14	-931.11	w	g	w/r	428.97	0.46	428.51	426.84	425.37	424.76	1407.38	1.5	ft	7	DL	5	2	13.81	ft	1393.4	DL
403	a	-551.81	-2342.98	w	g	w/r	430.17	0.76	429.41	426.82	425.56	424.95	1411.32	2.5	ft	11	DL	5	2	17.14	ft	1393.2	DL
404	a	-835.57	-980.38	w	g	w/r	431.40	1.26	430.13	427.13	425.43	424.82	1415.35	4.15	ft	14	DL	5	2	21.58	ft	1394.2	DL
405	a	-380.37	-623.21	w	g	w/r	431.61	0.58	431.03	426.58	425.54	424.78	1416.05	1.9	ft	16.5	DL	5	2.5	22.41	ft	1392.7	DL
405	b			w	g		431.68	0.64	431.04		417.41	416.35	1416.27	2.1	ft				3.5	50.3	ft	1323.7	DL

Well Number		LOCATION X (m)	LOCATION Y (m)	Well Description Codes			OPERATIONAL INFORMATION Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)	
405	c			w	g		431.46	0.43	431.03	423.70		423.69	1415.54	1.4	ft	25.46	M			25.49	ft		
405	d			w	g		431.54	0.49	431.06	423.78		420.48	1415.83	1.6	ft	25.46	M			36.31	ft		
405	e			w	p		431.16	0.24	430.92	404.91		404.86	1414.58	0.8	ft	86.15	M			86.3	ft		
406	a	-798.13	-758.69	w	g	w/r	432.19	0.79	431.40	427.13	424.93	424.47	1417.95	2.6	ft	16.6	DL	5	1.5	25.33	ft	1394.9	DL
407	a	-847.39	-646.32	w	g	w/r	433.05	0.82	432.23	426.70	424.81	424.35	1420.78	2.7	ft	20.85	DL	5	1.5	28.56	ft	1393.4	DL
408	a	-563.63	-426.16	w	g	w/r	433.49	0.55	432.94	426.09	424.34	423.88	1422.22	1.8	ft	24.3	DL	5	1.5	31.53	ft	1391.4	DL
409	a	139.87	-746.37	w	g	w/r	429.57	0.82	428.74	426.46	425.78	425.32	1409.34	2.7	ft	10.2	DL	5	1.5	13.93	ft	1392.6	DL
410	a	-798.13	-1214.40	w	g	w/r	430.47	0.90	429.57	427.27	425.44	424.98	1412.3	2.95	ft	10.5	DL	5	1.5	18	ft	1395.4	DL
411	a	-32.03	-55.19	o	g		430.79	0.96	429.83	424.34	422.82	422.36	1413.34	3.14	ft	21.14	DL	5	1.5			1385.7	DL
412	a	-786.30	-373.63	w	g	w/r	433.81	1.10	432.71	423.11	421.58	421.13	1423.25	3.6	ft	35.1	DL	5	1.5	41.6	ft	1381.7	DL
413	a	-983.36	-512.37	w	g	w/r	434.34	1.19	433.15	426.72	425.02	424.56	1425	3.9	ft	25	DL	5	1.5	32.09	ft	1393.6	DL
414	a	73.00	-301.41	w	g	w	431.03	0.90	430.13	424.63	423.14	422.68	431.026m	0.895	m	21	DL	5	1.5	8.342	m	1390.2	DL
415	a	-354.75	-118.26	w	g	w/r		0.69						0.694	m	28.35	DL	5	1.4	11.862	m	-37.23	DL
416	a	7.13	20.93	w	g	w	433.79	1.08	432.71	424.45	422.91	422.38	1423.19	3.54	ft	30.65	M	5	1.75	37.43	ft	1385.8	M
416	b	6.28	22.31	x	x		432.74	0.00	432.74	x	x	x	1419.76	0	ft	x	x	x	x	x	x	x	
417	a	63.48	23.49	w	g		432.25	0.65	431.60	416.10	415.49	414.93	1418.15	2.14	ft	53	DL	2	1.75	56.82	ft		
417	b	62.24	22.42	w	g		432.15	0.56	431.58	419.21	418.60	418.07	1417.81	1.85	ft			2	1.75	46.2	ft		
417	c	61.04	21.42	w	g	w	432.25	0.58	431.67	424.78	423.36	422.06	1418.15	1.9	ft	24.5	DL	5	3.5	33.45	ft		
417	d	63.77	21.92	w	g		432.22	0.73	431.50	422.62	422.01	421.30	1418.06	2.38	ft	31.5	DL	2	1.75	35.83	ft		
417	e	58.60	24.00	w	g		432.89	1.03	431.86			417.50	1420.24	3.37	ft					50.5	ft		
418	a	39.79	5.27	w	g	r	433.05	0.85	432.20	415.78	415.17	414.63	1420.77	2.78	ft	56	DL	2	1.75	60.42	ft	1386.3	P
418	b	38.82	4.59	w	g	r	432.85	0.67	432.18	419.40	418.79	418.25	1420.1	2.19	ft	43.75	DL	2	1.75	47.88	ft		
418	c	39.90	3.93	w	g	r	432.37	0.21	432.15	423.14	422.53	422.00	1418.53	0.7	ft	31.5	DL	2	1.75	34.03	ft		
418	d	37.72	3.74	w	g	w/r	432.66	0.46	432.20	424.59	423.07	422.53	1419.48	1.5	ft	28	DL	5	1.75	33.22	ft		
419	a	18.76	-10.48	w	g		432.67	0.19	432.49	422.45	421.84	421.30	1419.53	0.61	ft	33.25	DL	2	1.75	37.3	ft		
419	b	17.06	-12.11	w	g		432.34	0.40	431.94			418.24	1418.44	1.3	ft					46.27	ft		
419	c	16.05	-13.06	w	g	w	432.80	0.51	432.29	424.09	422.57	422.11	1419.96	1.68	ft	26.18	DL	5	1.5	35.09	ft	1387.3	DL
420	a	-4.99	-27.79	o	g		432.45	0.18	432.27		421.78		1418.8	0.6	ft					35	ft		
420	b	-3.57	-27.07	w	g	w	432.68	0.45	432.23	419.74	419.13	418.59	1419.54	1.47	ft	42.45	M	2	1.75	46.2	ft	1373.3	M
420	c	-2.43	-26.07	w	g		432.64	0.40	432.24	416.44	415.83	415.29	1419.41	1.3	ft	53.15	M	2	1.75	56.9	ft	1362.5	M
420	d	-5.91	-28.69	o	g		432.83	0.52	432.31	424.36	422.62	422.16	1420.05	1.7	ft	27.8	DL	5	1.5	35	ft	1385.8	DL
421	a	-25.91	-51.77	o	g		430.55	0.59	429.96			421.25	1412.56	1.93	ft					30.5	ft		
421	b	-26.71	-57.84	o	p	w	430.61	0.67	429.94	424.51	422.99	422.38	1412.75	2.19	ft	20	DL	5	2			1385.8	DL
421	c	-24.45	-52.38	x	x		430.24	0.00	430.24	x	x	x	1411.3	0	ft	x		x	x	x	x	x	x
422	a	-35.75	-54.55	o	g		430.24	0.29	429.94				1411.54	0.96	ft								
423	a	-12.88	-35.93	o	g		432.76	0.92	431.83			422.24	1419.81	3.03	ft							1385.3	P
425	a			w	g	w/r										13.7	DL	5	1.5			-20.2	DL
426	a	-195.14	-1386.80	w	g	w/r		0.70						2.3	ft	6.27	M						

Well Number		LOCATION X (m)	LOCATION Y (m)	Well Description Codes			OPERATIONAL INFORMATION Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)	
427	a	-1328.20	-622.90	w	g	w/r		0.58						1.9	ft	5.87	M						
501	a	181.47	312.33	w	g											3.75	DL	2.5	4			-44	DL
501	b	lake		w	g											13.5	DL	2.5	4			-20	DL
501	c	lake		w	g											42.5	DL	2.5	3			-48	DL
502	a	-786.30	-327.63	w	g	w/r	436.41	0.49	435.92	410.81	410.40	407.88	1431.8	1.6	ft	84	M/P		6	91.35	ft	1338.2	DL
503	a	49.66	-482.95	w	g	r	430.69	0.82	429.86	406.39	404.56	401.71	430.685m	2.7	ft	79.7	DL	6	8	>20	m	1318	DL
504	a	51.53	-484.50	w	g	r	430.61	0.76	429.84	419.18	419.57	417.39	430.605m	2.5	ft	37.5	DL	2	5	12.56	m	1369.4	DL
505	a	-354.75	-118.26	w	g	r	434.38	1.35	433.03	414.06	413.45	412.84	434.383m	1.35	m	68.3	DL	2	2	70.674	ft	-72.3	DL
506	a	-19.44	30.71	w	p		432.79	0.61	432.18	423.85	422.79	422.33	1419.9	2	ft	29.3	DL	8	1.5	34.29	ft	1384.1	DL
507	a	-21.78	9.80	w	p		433.04	0.36	432.68	423.87	422.35	421.87	1420.75	1.19	ft	30.1	M	5		36.65	ft		
508	a	-16.77	52.14	w	p		430.61	0.58	430.03	423.31	421.79	421.76	1412.76	1.89	ft	23.95	M	5		29.03	ft		
509	a	0.74	48.95	w	p		432.30	0.42	431.88	423.34	421.82	421.89	1418.31	1.39	ft	29.4	M	5		34.17	ft	1386	P
510	a	13.08	45.45	w	p		432.93	0.26	432.67	423.97	422.44	421.79	1420.38	0.86	ft	29.4	M	5	2.12	36.55	ft	1383.9	M
511	a	39.15	34.45	w	g		432.74	0.34	432.41	424.03	422.51	422.04	1419.76	0.337	m	28.58	M	5		35.1	ft		
512	a	22.18	13.49	w	g		432.83	0.43	432.40	424.45	422.92	422.24	1420.04	1.4	ft	27.5	M	5		34.73	ft		
513	a	6.56	19.39	w	p		433.02	0.37	432.65	423.97	422.45	421.99	1420.68	1.21	ft	29.7	M	5	1.5	36.19	ft	1384.5	M
514	a	-6.20	24.72	w	p		433.10	0.09	433.00	424.19	422.66	421.93	1420.93	0.31	ft	29.24	M	5		36.64	ft		
515	a	26.39	74.84	w	p	w	433.50	0.52	432.98	423.75	422.40	421.94	1422.26	1.71	ft	32	M	5	1.5	37.94	ft	1384.4	M
515	b	25.85	73.78	w	p		433.50	0.55	432.95	420.11	420.68	420.23	1422.25	1.82	ft	43.92	M	2	1.5	43.55	ft	1380.8	M
516	a	36.66	61.69	w	p	w	433.92	0.54	433.38	423.88	422.35	421.88	1423.62	1.76	ft	32.95	M	5		39.5	ft		
517	a	9.14	67.22	w	p	w	432.45	0.82	431.63	424.18	422.66	422.22	1418.79	2.68	ft	27.11	M	5		33.55	ft		
518	a	0.53	-1.11	w	p	w	432.96	0.41	432.56	424.18	422.64	422.18	1420.48	1.33	ft	28.8	M	5	1.5	35.36	ft	1385.2	M
518	g	0.84	-0.36	g	s		433.00	0.34	432.66	x	x	x	432.997m	1.1	ft	x	x	x	x	x	x	x	x
519	a	-9.23	1.84	w	p	w	433.11	0.44	432.67	423.87	422.35	422.35	1420.95	1.44	ft	30.3	M	5		35.28	ft		
520	a	-10.19	-11.16	w	p	w	432.94	0.40	432.55	423.65	422.12	422.26	1420.42	1.3	ft	30.5	M	5		35.065	ft		
521	a	-28.70	-29.49	w	p	w	432.16	0.40	431.77			422.54	1417.86	1.3	ft					31.59	ft		
522	a	-12.24	-29.54	o	p		432.77	0.49	432.28	424.56	423.04	422.16	1419.85	1.62	ft	26.93	M	5				1385.1	P
523	a	-53.58	-115.69	w	p	w	430.71	0.52	430.19	424.30	422.95	422.49	1413.1	1.7	ft	21.05	DL	5	1.5	26.98	ft	1385.6	DL
524	a				g	r		0.70		409.38	408.77	408.01		2.3	ft	1343.1	DL	2	2.5			1338.6	DL
525	a			w	g	r	427.92	0.85	427.06	416.15		414.49	1403.93	2.8	ft	38.61	M			44.05	ft		
526	a	128.07	-150.12	w	p	w	426.85	0.69	426.16	421.17	420.56	412.12	1400.42	2.26	ft	18.64	DL	2		14.73	m		
527	a	47.51	112.90	w	p	w	433.98	0.59	433.39			421.94	1423.82	1.95	ft					39.49	ft		
528	a	23.49	107.79	w	p	w	434.35	0.70	433.66	423.88	422.36	421.91	1425.04	0.695	m	34.36	M	5		40.83	ft		
529	a	34.77	116.02	w	p	w	433.93	0.69	433.25	423.78	422.25	421.75	1423.66	2.25	ft	33.32	M	5		39.97	ft		
530	a	10.56	32.61	w	p	w	433.29	0.68	432.61	422.86	421.33	420.87	1421.57	2.23	ft	34.25	M	5	1.5	11.633	m	1383.4	M
530	b	10.56	32.02	w	p		433.24	0.34	432.90	422.26	421.65	421.20	1421.38	1.11	ft	36	M	2	1.5	38.36	ft	1381.5	M
530	c	10.00	31.24	w	p		433.23	0.31	432.92	420.43	419.92	419.47	1421.35	1.01	ft	42	M	2	1.5	45.15	ft	1376.3	
530	g	10.37	33.66	g	s		433.14	0.30	432.83	x	x	x	1421.05	0.99	ft	x	x	x	x	x	x	x	x

Well Number		LOCATION X (m)	Y (m)	Well Description Codes			OPERATIONAL INFORMATION Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)	
531	a	3.57	9.12	w	p	w	433.23	0.75	432.48	423.26	422.12	421.67	1421.37	2.47	ft	32.73	M	2	1.5	37.95	ft	1383.5	M
531	g	4.07	10.03	g	s		432.76	0.32	432.44	x	x	x	1419.8	1.05	ft	x	x	x	x	x	x	x	x
532	a	-3.64	-10.97	w	p	w	432.86	0.49	432.37	424.30	422.51	422.05	1420.16	1.62	ft	28.1	M	5	1.5	10.814	m	1384.7	M
532	b	-3.66	-11.64	w	p		432.76	0.41	432.35	417.22	417.06	416.61	1419.82	1.35	ft	51	M	0.5	1.5	11.462	m	1382.2	M
532	c	-3.68	-12.30	w	p		432.77	0.41	432.37	420.96	420.30	419.84	1419.86	1.33	ft	38.75	M	0.5	1.5	12.932	m	1377.4	M
532	d	-3.63	-9.10	w	p		432.60	0.22	432.38	417.67	417.05	416.60	1419.3	0.72	ft	49	M	0.5	1.5	16.007	m	1366.8	M
532	g	-3.46	-10.07	g	s		432.57	0.18	432.39	x	x	x	1419.19	0.6	ft	x	x	x	x	x	x	x	x
533	a	-7.96	-20.53	w	p	w	433.00	0.55	432.45	424.21	422.69	422.23	1420.6	1.8	ft	28.82	M	5	1.5	10.764	m	1385.3	M
533	b	-7.97	-21.32	w	p		432.66	0.19	432.47	421.92	421.61	421.15	1419.48	0.62	ft	35.24	M	0.5	1.5	11.504	m	1381.7	M
533	c	-7.98	-21.91	w	p		432.58	0.12	432.45	420.91	420.09	419.63	1419.21	0.4	ft	38.27	M	2	1.5	12.945	m	1376.7	M
533	d	-7.28	-18.72	w	p		432.87	0.30	432.56	423.72	423.66	422.99	1420.17	1	ft	30	DL	2	2.2	9.875	m	1387.8	M
533	g	-7.96	-19.67	g	s		432.71	0.31	432.40	x	x	x	1419.65	1.02	ft	x	x	x	x	x	x	x	x
534	a	-11.57	-31.79	o	p		432.73	0.58	432.15				1419.73	1.91	ft								
534	b	-11.52	-31.16	w	p	w	432.65	0.50	432.15	422.94	422.57	421.96	1419.47	1.64	ft	31.87	DL	0.5	2	35.095	ft	1385.1	DL
534	g	-11.04	-30.06	g	s		432.54			x	x	x	1419.08	x	x	x	x	x	x	x	x	x	x
601	g	-14.66	-36.95	g	s		432.20	0.21	431.98	x	x	x		0.7	ft	x	x	x	x	x	x	x	x
602	a	260.85	-131.38	w	p	w/r	426.56	0.43	426.14	413.67		422.56	426.563m	1.4	ft	42.3	M			4	m		
602	b	259.96	-130.59	w		r	426.60	0.40	426.21	416.20		419.98	426.601m	1.3	ft	34.14	M			6.617	m		
602	c	259.31	-129.64	w		r	426.86	0.52	426.34	420.20			426.856m	1.7	ft	21.83	M						
602	d	258.66	-128.82	w		r	426.40	0.21	426.19	422.37			426.404m	0.7	ft	13.24	M						
602	e	253.14	-132.60	w		r	426.40	0.40	426.00	420.19			426.397m	1.3	ft	20.36	M						
602	f			w		r		0.52						1.7	ft	21	M						
603	a	-66.84	-162.71	w	p	w	430.91	0.11	430.81	423.02	421.49	421.04	430.912m	0.35	ft	25.9	M	5		8.526	m		
603	g	-65.13	-162.97	g	s		431.26	0.40	430.86	x	x	x	1414.89	1.31	ft	x	x	x	x	x	x	x	x
604	a	-41.15	-83.28	o	p		430.29	0.24	430.05				1411.7	0.78	ft								
604	b	-41.39	-79.09	w	p	w	430.72	0.60	430.12	422.25	421.61	421.00	1413.12	1.97	ft	27.8	DL	1.5	2	31.88	ft	1382.8	DL
604	g	-41.76	-82.23	g	s		430.22	0.31	429.91	x	x	x	1411.47	1.02	ft	x	x	x	x	x	x	x	x
605	a	29.47	96.94	w	p	w	434.04	0.37	433.67	424.30	422.78	422.33	1424.01	1.2	ft	31.94	M	5		38.42	ft		
606	a	-71.61	-143.89	w	p		431.11	0.58	430.54			405.60	1414.41	1.89	ft					83.71	ft		
607	a	11.32	-22.72	w	p		432.86	0.56	432.30	409.39	408.68	408.52	1420.15	0.56	m	77	DL	2	0.5	79.85	ft	1340.6	DL
701	a	-43.84	56.21	w	p	w	427.01	0.76	426.25			422.53	427.006m	2.48	ft					14.7	ft		
702	a	-60.34	40.07	w	p	w	427.64	0.53	427.11	424.49	422.97	422.42	427.642m	1.74	ft	10.33	M	5		17.12	ft		
702	b	-57.87	41.09	w	p		427.61	0.67	426.93	411.29	410.68	410.07	427.608m	2.21	ft	53.55	DL	2	2	57.55	ft		
702	c	-60.77	40.72	w	p		427.79	0.63	427.15	420.17	420.01	419.56	427.786m	2.08	ft	25	DL	0.5	1.5	27	ft		
703	a	-49.13	18.96	w	p	w	431.65	0.99	430.66	424.24	422.71	422.46	1416.19	3.26	ft	24.34	M	5		30.18	ft		
704	a	31.54	101.79	w	p		434.03	0.35	433.68			410.75	1423.99	1.14	ft					76.37	ft		
705	a	10.63	45.04	w	p		433.43	0.73	432.70			408.86	1422.03	2.4	ft					80.64	ft		
706	a	-37.72	-3.91	w	p	w	433.05	0.88	432.18	424.27	422.74	422.13	1420.78	2.88	ft	28.83	DL	5	2	35.83	ft		

Well Number		LOCATION X (m)	LOCATION Y (m)	Well Description Codes			OPERATIONAL INFORMATION Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)	
706	b	-36.90	-4.36	w	p		432.78	0.57	432.21			421.57	1419.87	1.87	ft					36.77	ft		
707	a	-54.13	-117.62	w	p	w	430.99	0.81	430.18	423.87	422.35	421.92	1414.02	2.66	ft	23.36	DL	5		29.77	ft		
707	b	-52.99	-119.71	w	p		431.23	0.98	430.25	421.26	421.11	420.57	1414.8	3.21	ft	32.71	DL	0.5		34.99	ft		
707	c	-52.00	-117.38	w	p		431.01	0.70	430.31	419.43	419.27	418.59	1414.08	2.31	ft	38.01	DL	0.5		40.75	ft		
707	d	-51.81	-115.56	w	p		431.12	0.79	430.33	416.40	416.25	415.78	1414.43	2.58	ft	48.28	DL	0.5		50.33	ft		
708	a	-62.33	-143.77	w	p	w	431.87	1.01	430.86	424.94	423.41	422.25	1416.9	3.31	ft	22.75	M	5		31.58	ft		
709	a	-74.74	-184.01	w	p	w	432.15	0.97	431.17	424.91	423.38	422.70	1417.8	3.19	ft	23.75	M	5		9.441	m		
710	a	-68.86	-2.61	w	p	w	432.67	0.80	431.87	424.25	423.17	422.25	1419.52	2.62	ft	27.62	DL	5	3	34.17	ft	1383.9	DL
801	a	24.44	62.92	w	p	w	433.65	0.67	432.98	423.57	421.89	421.58	1422.74	2.2	ft	33.08	M	5	1	39.6	ft	1383.2	M
801	b	23.40	64.48	w	p		433.73	0.82	432.90	418.30	417.67	417.22	1422.99	2.7	ft	50.62	M	2	1.5	54.17	ft	1368.9	M
802	a			x	x		432.25	0.00	432.25	x	x	x	1418.14	0	ft	x	x	x	x	x	x	X	x
803	a			x	x		432.40	0.00	432.40	x	x	x	1418.63	0	ft	x	x	x	x	x	x	X	x
804	a			x	x		432.34	0.00	432.34	x	x	x	1418.45	0	ft	x	x	x	x	x	x	X	x
805	a	-21.84	-29.12	o	p		432.64	0.51	432.13				1419.43	1.68	ft			0.5					
806	a	27.56	84.24	w	p		434.17	0.90	433.27			418.58	1424.44	2.94	ft					51.13	ft		
807	a	32.76	73.84	w	g	w	433.23	0.24	432.99	422.72	422.42	422.42	1421.36	0.24	m			1	0	35.47	ft		
807	b			w	g		433.23	0.22	433.01	422.86	422.55	422.55	1421.36	0.22	m			1	0	35.03	ft		
808	a	22.36	71.24	w	g	w	432.79	0.15	432.64			422.07	1419.93	0.5	ft					35.17	ft		
809	a	32.76	70.72	x	x		432.28	0.00	432.28	x		x	1418.24	0	ft	x		x	x	x		X	
811	a	-47.75	-57.68	x	x		430.53	0.00	430.53				1412.49	0	ft							X	
812	a	-8.94	-84.23	w	g	w	432.46	0.84	431.62	424.31	422.79	422.65	1418.83	0.84	m	26.73	DL	5		9.805	m		
813	a	30.72	-103.99	w	g		429.22	1.01	428.21	416.34	416.30	415.38	1408.193	3.3	ft	42.25	DL	2	3	45.384	ft	1360.9	DL
814	a	-81.93	-71.07	x	x		432.74	0.00	432.74	x	x	x	1419.75	0	ft	x	x	x	x	x	x	x	x
815	a	-90.55	-124.29	x	x		431.55	0.00	431.55	x	x	x	1415.84	0	ft	x	x	x	x	x	x	x	x
815	b	-87.36	-145.60	w	p	w		0.57						0.57	m	26.6	DL	5	1	9.489	m	-32.6	DL
816	a	-12.55	-173.53	x	x		428.24	0.00	428.24	x	x	x	1405	0	ft	x	x	x	x	x	x	x	x
816	b	-10.63	-171.46	w	p	w	429.27	0.57	428.70	424.31	423.01	422.70	1408.35	0.57	m	16.26	DL		1	21.533	ft	-21.1	DL
817	a	50.41	-27.04	x	x		432.11	0.00	432.11	x	x	x	1417.68	0	ft	x	x	x	x	x	x	x	x
818	a	6.78	43.95	x	x		432.68	0.00	432.68	x	x	x	1419.56	0	ft	x	x	x	x	x	x	x	x
819	a	39.70	33.3	x	x		432.68	0.00	432.68	x	x	x	1419.56	0	ft	x	x	x	x	x	x	x	x
820	a	49.54	149.44	w	p	w	433.23	0.54	432.69	423.09	421.53	421.53	433.227m	0.54	m	33.25	DL	5	0	38.39	ft	1383.1	DL
910	a	-82.93	-121.07	w	g		432.02	0.61	431.41			422.52	1417.4	0.61	m					9.504	m		
911	a			w	g	w		0.85						2.8	ft	31.08	M			34.285	ft		
912	a	14.01	-53.32	w	g	w	432.51	0.90	431.61	423.06		421.83	1418.99	2.94	ft	31	M			10.675	m		
913	a	-12.82	-71.80	w	g	w	431.45	0.58	430.88			422.84	1415.53	1.89	ft					8.618	m		
915	a	160.13	-61.74	w	g	w	431.12	0.45	430.67			422.15	1414.42	0.45	m					8.97	m		
916	a	100.62	-79.58	w	g	w	428.62	0.70	427.91	419.50		421.21	1406.22	2.3	ft	29.9	M			7.41	m		
918	a	-25.16	-29.81		g		433.21	1.21	432.00				433.214m	3.98	ft								

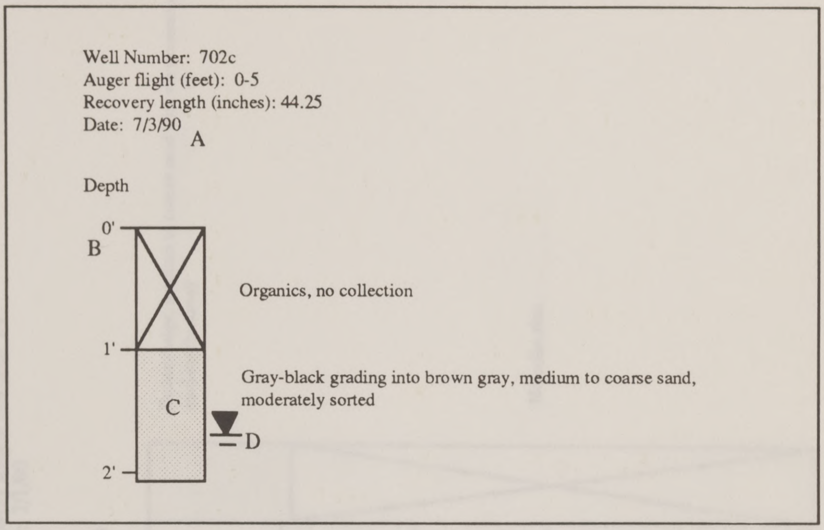
Well Number		LOCATION X (m)	LOCATION Y (m)	Well Description Codes			OPERATIONAL INFORMATION Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)	
919	a	154.92	-29.71	w	g	w	432.12	1.06	431.06			422.70	1417.72	1.06	m					9.426	m		
925	a	75.55	183.18	w	g		433.60	1.23	432.36	424.24	422.77	422.23	1422.56	1.232	m	30.69	M	5	1.75	11.362	m	1385.2	
925	b	75.20	184.60	w	g		433.47	1.15	432.32	407.09	337.84	404.16	1422.16	1.152	m	86.57	DL	3	1.75	96.17	ft	1330.6	DL
925	c	76.72	184.24	w	g		433.42	1.08	432.33	424.32	421.71	421.18	1421.97	1.083	m	29.86	DL	5	1.75	12.235	m	1394.9	DL
925	d	74.99	181.98	p	b	w	431.65	0.53	431.12				1416.19	1.75	ft								
926	a	230.72	145.65	w	g	w		0.92						0.915	m	28.27	M	5	1.75	34.75	ft	-35.02	M
927	a	225.87	-55.13	w	g	w/r	431.66	0.93	430.73			422.64	1416.193	3.05	ft					29.57	ft		
950	a	90	100	x	x		432.07	0.00	432.07	x	x	x	1417.56	0	ft	x	x	x	x	x	x	x	x
951	a	64	105	x	x		432.88	0.00	432.88	x	x	x	1420.22	0	ft	x	x	x	x	x	x	x	x
952	a	80	118	x	x		433.54	0.00	433.54	x	x	x	1422.38	0	ft	x	x	x	x	x	x	x	x
953	a	-17	130	x	x		433.11	0.00	433.11	x	x	x	1420.97	0	ft	x	x	x	x	x	x	x	x
954	a	43.75	123.089	w	p	w	434.07	0.84	433.23	421.86	422.29	421.47	434.068m	2.75	ft	40.05	DL	2.05	2.7	41.33	ft	1376.6	DL
954	b	43.76	122.395	w	p		434.21	0.76	433.45	423.78	420.92	420.46	434.207m	2.49	ft	34.2	DL	5	1.5	45.1	ft	1383.9	DL
955	a	54.30	169.766	w	p		433.93	0.62	433.31	423.16	421.49	421.08	433.933m	0.62	m	35.35	DL	0.5	1.35	12.85	m	1379.6	DL
955	b	54.53	170.263	w	p	w	433.72	0.39	433.33	423.16	422.08	421.62	433.719m	0.39	m	34.64	DL	5	1.5	12.1	m	1381.9	DL
956	a	-24.48	-164.84	w	p	w	430.83	0.85	429.98	424.54	423.01	422.71	430.831m	2.8	ft	23	DL	5	1	26.65	ft	-29	DL
957	st	-18.00	-220	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
957	a	-13.20	-219.359	w	p	w	428.65	0.84	427.81			422.53	1406.328	0.84	m					20.07	ft		
957	b	-13.16	-218.34	w	p		428.73	0.84	427.89			421.19	1406.588	0.84	m					24.73	ft		
958	a	42.806	-107.313	o	p	w	428.40	0.58	427.82			422.81	428.399m	1.89	ft					5.588	m		
959	nest			o	p		428.53	0.58	427.95				1405.935	1.9	ft								
975	a	106	-160.16	x	x		425.55	0.00	425.55	x	x	x	1396.15	0	ft	x	x	x	x	x	x	x	x
976	a	108.54	-167.53	o	p		425.99	0.82	425.17				1397.6	2.7	ft								
977	a	110.34	-182.08	o	p		425.31	0.54	424.77				1395.36	1.77	ft								
978	a	105.02	-148.86	o	p		426.42	0.49	425.93				1399.03	1.62	ft								
979	a	101.833	-137.13	o	p		426.39	0.46	425.94				1398.932	1.5	ft								
980	a	100.37	-130.55	o	p		426.35	0.46	425.89				1398.78	1.5	ft								
981	a	97.063	-115.39	x	x		425.99	0.00	425.99	x	x	x	1397.589	0	ft	x	x	x	x	x	x	x	x
982	a	90.7	-77.22	w	p	w	428.28	0.48	427.81			422.18	1405.121	1.56	ft					20.03	ft		
983	a	147.769	-263.449	w	p	w	425.221	0.34	424.89		422.66	422.20	425.221m	1.1	ft				1.5	9.9	ft		
984	a	45.773	-163.676	w	p	w	430.426	0.16	430.26		422.91	422.45	430.426m	0.54	ft				1.5	26.16	ft		
001	a	52.533	-25.371	w	p	w	432.640	0.54	432.10	423.50	421.97	421.51	432.64m	1.78	ft	30	DL	5	1.5	36.5	ft		
002	a	92.815	-272.146	w	g	w	426.283	0.05	426.23	423.84	422.93	422.78	426.283m	0.17	ft	8	DL	3	0.5	11.5	ft		
003	a	96.729	-266.042	w	p	w	425.647	1.12	424.52	423.97	423.67	423.62	425.647m	3.69	ft	5.49	DL	1	0.17	2.029	m		
004	a	85.73	-284.934	w	g	w	429.929	0.93	429.00	424.75	423.22	423.22	429.929m	3.04	ft	17	DL	5	0	22	ft		
005	a	62.338	-204.794	w	g	w	427.854	0.76	427.09	424.04	423.13	422.97	427.854m	2.5	ft	12.51	DL	3	0.5	4.88	m		
006	a	51.262	-203.016	w	g	w	429.968	0.63	429.33	423.87	422.96	422.81	429.968m	2.08	ft	20	DL	3	0.5	23.5	ft		
007	a	74.037	-207.439	w	p	w	425.448	0.66	424.79	424.43	424.13	423.67	425.448m	2.17	ft	4.71	DL	1	1.5	5.83	ft		

Well Number		LOCATION X (m)	LOCATION Y (m)	Well Description Codes			OPERATIONAL INFORMATION: Measuring Point (MP) Elevation (m)	Stick Up (m)	Land Surface Elevation (m)	Screen Top (ST) Elevation (m)	Screen Bottom Elevation (m)	Well Bottom Elevation (m)	ORIGINAL DATA: Measuring Point Elevation (ft)	Stick Up w/units		Depth to ST from MP (ft)		Screen length (ft)	Tailpipe length (ft)	Total depth from MP w/units		Elevation of Total Depth (ft)
008	a	141.11	-263.104	w	p	w	425.528	0.36	425.17	424.06	423.75	423.70	425.528m	1.17	ft	4.83	DL	1	0.17	6	ft	
009	a	127.299	-261.83	w	p	w	424.589	0.11	424.47	423.86	423.56	423.51	424.589m	0.375	ft	2.38	DL	1	0.17	3.55	ft	
010	a	152.258	-263.264	w	p	w	425.438	0.97	424.47	424.00	423.70	423.66	425.438m	3.17	ft	4.71	DL	1	0.125	5.83	ft	
011	a	112.422	-275.035	w	p	w	424.717	0.11	424.60	423.74	423.47	423.42	424.717m	0.375	ft	3.21	DL	0.875	0.17	4.25	ft	
012	a	73.044	-230.043	w	p	w	425.312	0.30	425.01	424.04	423.74	423.69	425.312m	1	ft	4.17	DL	1	0.17	5.33	ft	
013	a			o																		
014	a			o																		
015	a	-22.358	-50.29	o			431.05															
016	a	-31.248	-61.332	o			430.45															
017	a	-35.93	-71.323	o			430.03															
018	a	-40.945	-81.599	o			430.82															
019	a	-73.402	64.82	w	p	w	431.477	0.59	430.89	424.30	422.77	422.32	431.477m	1.92	ft	23.55	DL	5	1.5	9.16	m	
020	a	87.973	-22.963	w	p	w	432.138	0.66	431.48	424.49	422.97	422.51	1417.339	2.17	ft	25.08	DL	5	1.5	31.58	ft	
021	a	125.25	-333.527	w	p	w	430.197	0.61	429.59	423.80	423.64	423.19	430.197m	2	ft	21	DL	0.5	1.5	23	ft	

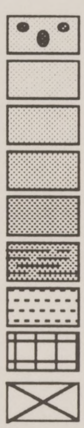
STAFF LOCATION	X (m)	Y (m)				Measuring Point (MP) Elevation (m)		Measuring Point Elevation (ft)	REMARKS
Wetland	113.32	-197.38			w	424.51		1392.76	MP at 3.34 ft mark
Unnamed Lake					w				MP at 3.34 ft mark

Appendix A2 Visual Core Descriptions

Explanation



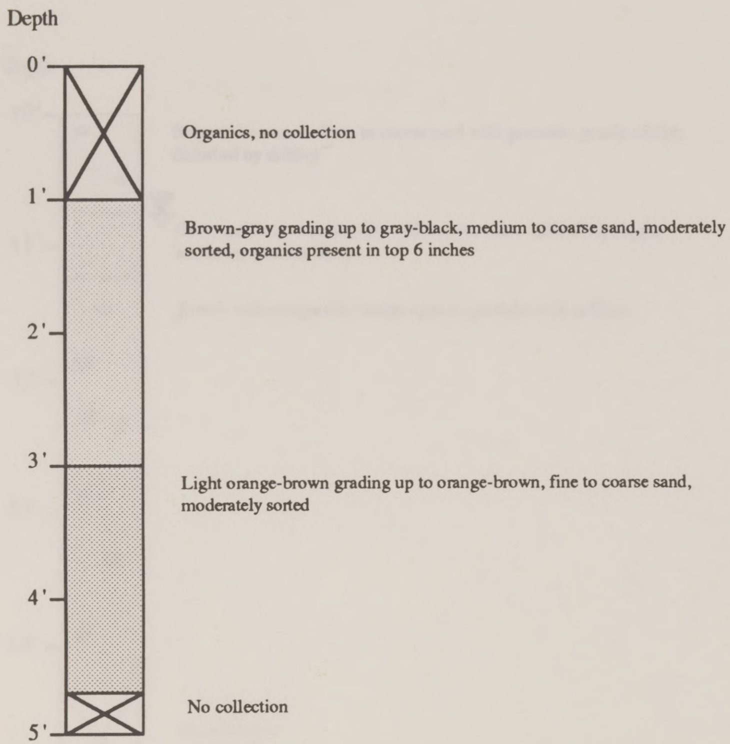
A -- Date of drilling and core collection
B -- Depth of core sediments, scale for all core descriptions is 1" = 1.42 ft depth. Depths were measured in feet and are displayed as such in this appendix. When referred to in text, these values are converted to elevation in meters above mean sea level.
C -- Symbols of geologic sediments



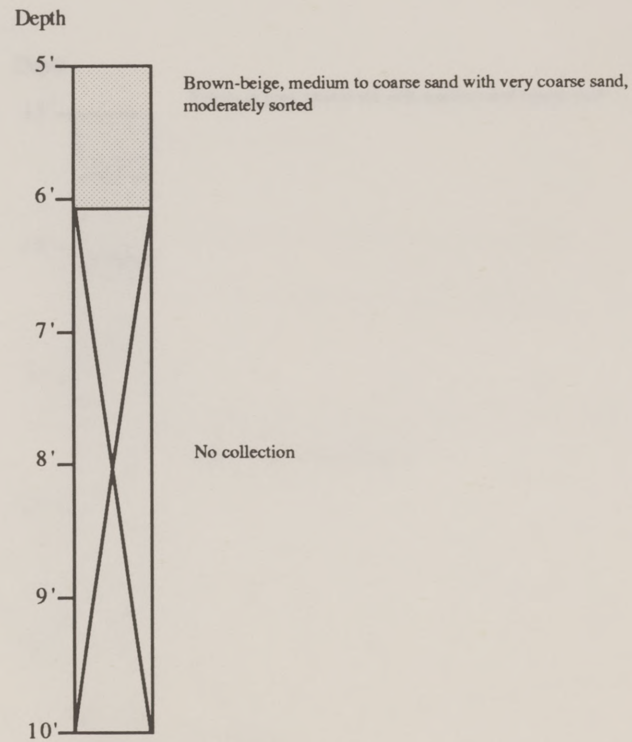
Sediment containing granules and pebbles
Coarse to very coarse sand
Medium sand
Fine to medium sand
Very fine sand
Coarse silt and sand
Coarse silt
Tree material
No collection

D -- Water table location determined during drilling from condition of sediments.

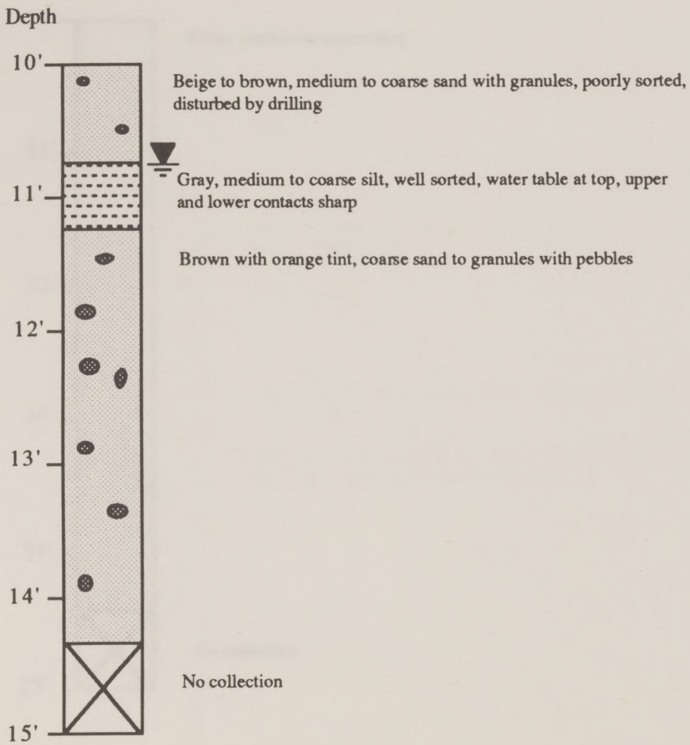
Well Number: 702c
Auger flight (feet): 0-5
Recovery length (inches): 44.25
Date: 7/3/90



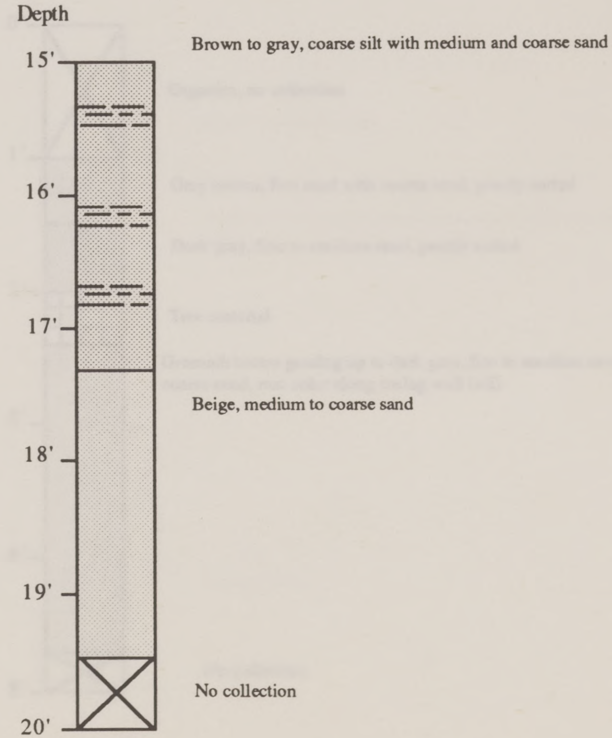
Well Number: 702c
Auger flight (feet): 5-10
Recovery length (inches): 13
Date: 7/1/90



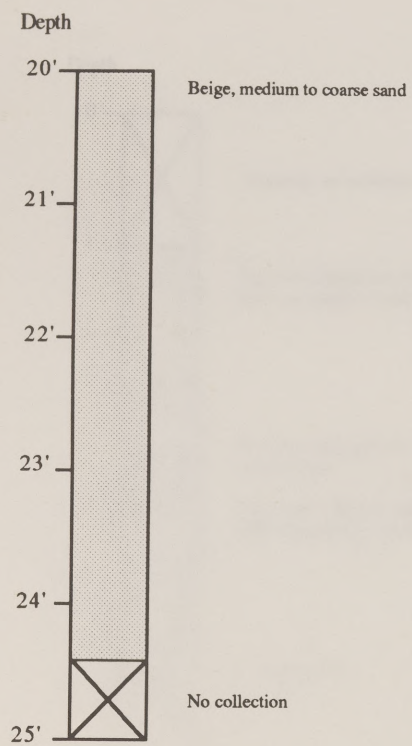
Well Number: 702c
Auger flight (feet): 10-15
Recovery length (inches): 52
Date: 7/1/90



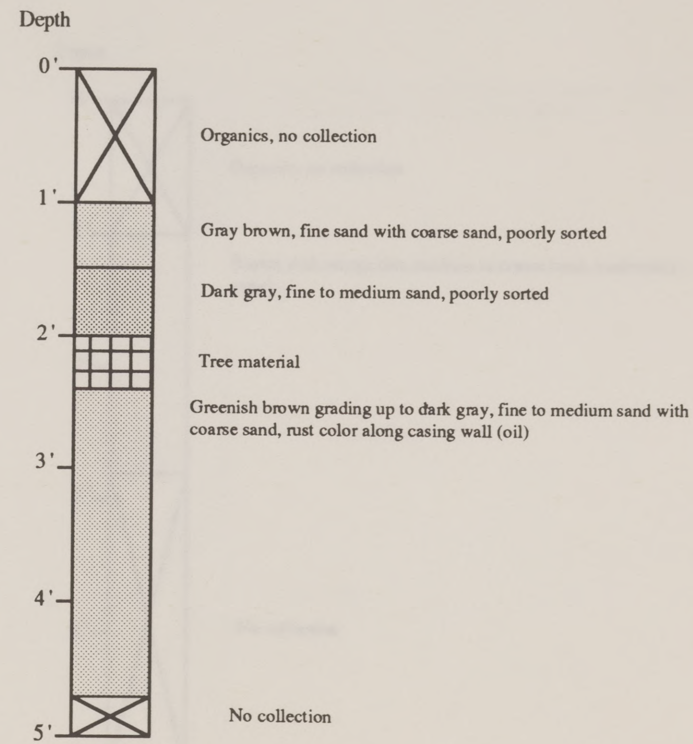
Well Number: 702c
Auger flight (feet): 15-20
Recovery length (inches): 54
Date: 7/1/90



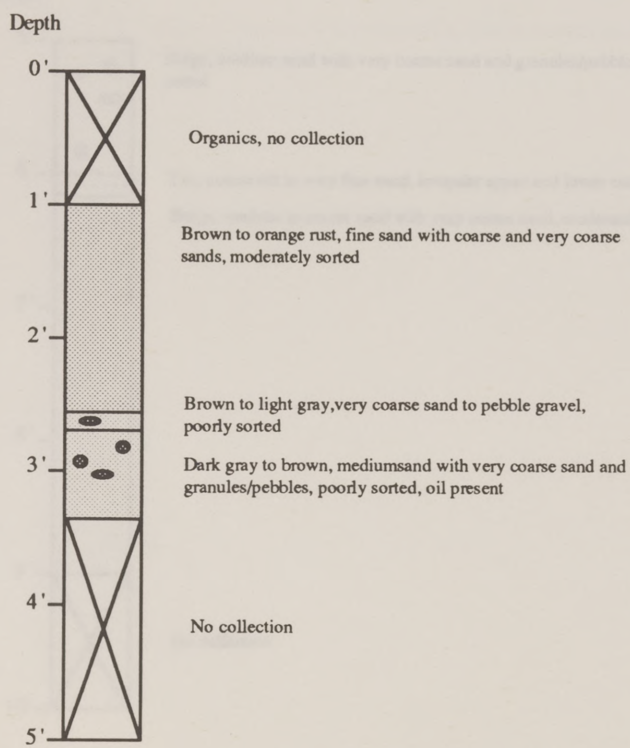
Well Number: 702c
Auger flight (feet): 20-25
Recovery length (inches): 53.5
Date: 7/1/90



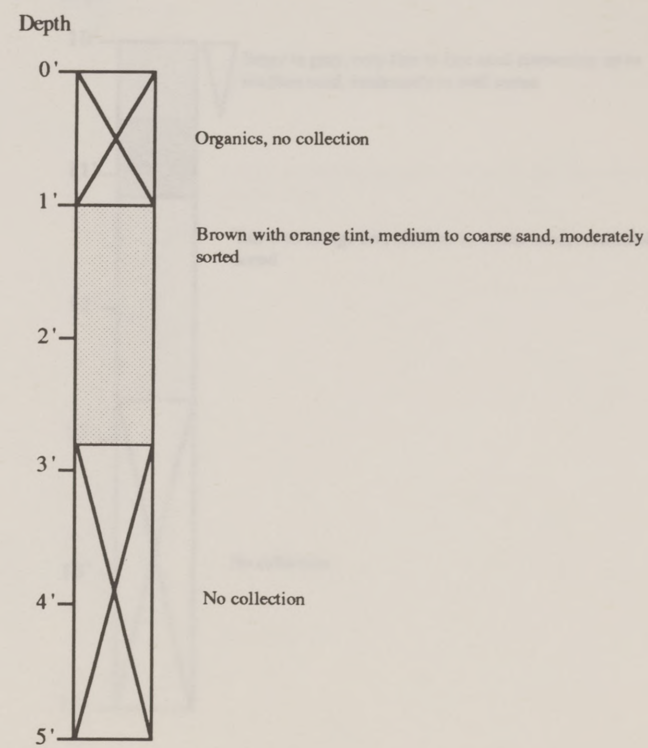
Well Number: 980
Auger flight (feet): 0-5
Recovery length (inches): 44
Date: 10-26-89



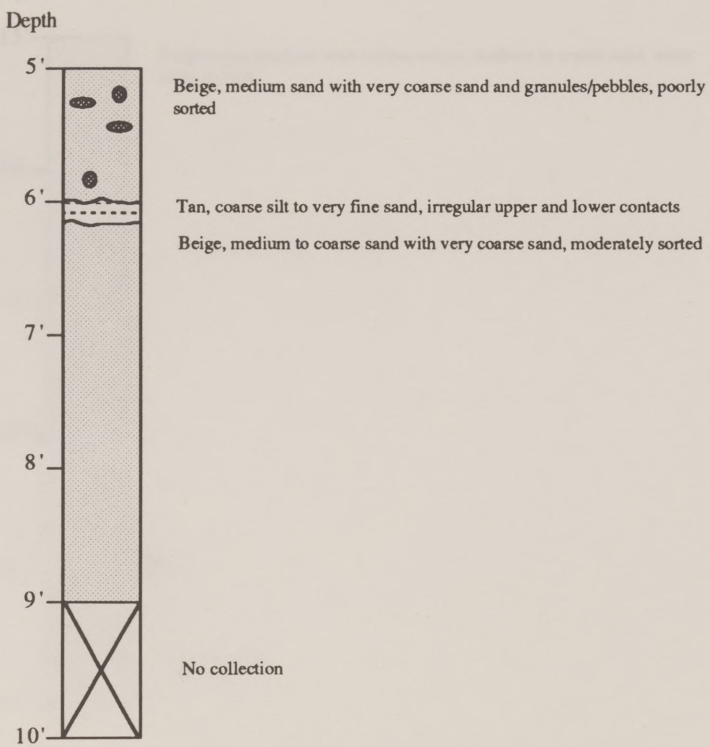
Well Number: 981
Auger flight (feet): 0-5
Recovery length (inches): 28.5
Date: 10-27-89



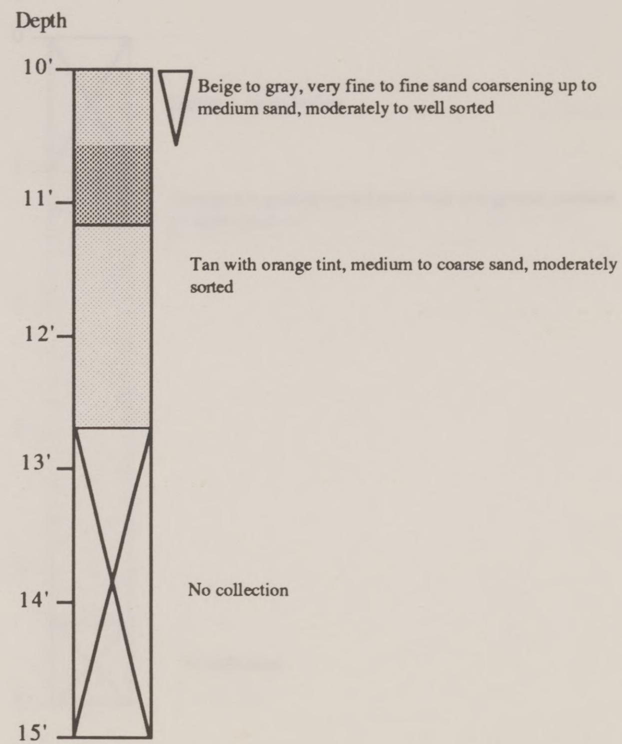
Well Number: 982
Auger flight (feet): 0-5
Recovery length (inches): 34
Date: 10-27-89



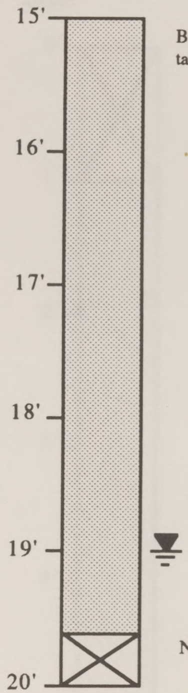
Well Number: 982
Auger flight (feet): 5-10
Recovery length (inches): 48
Date: 10/27/89



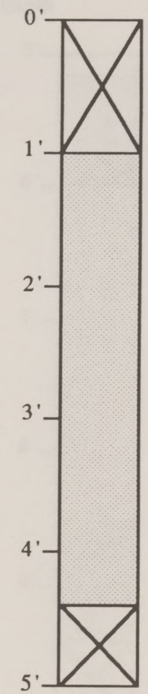
Well Number: 982
Auger flight (feet): 10-15
Recovery length (inches): 32.5
Date: 10/27/89



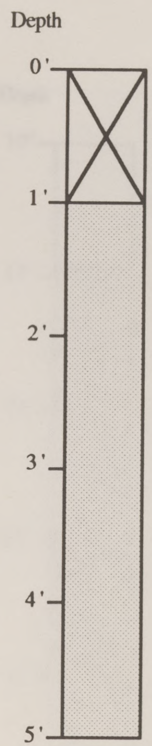
Well Number: 982
Auger flight (feet): 15-20
Recovery length (inches): 55.5
Date: 10/28/89



Well Number: 983
Auger flight (feet): 0-5
Recovery length (inches): 41
Date: 10-28-89



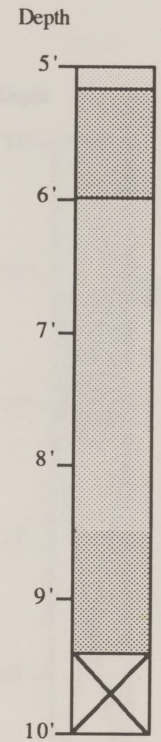
Well Number: 984
Auger flight (feet): 0-5
Recovery length (inches): 48.25
Date: 10-28-89



Organics, no collection

Brown grading into beige, fine-medium sand with coarse sand coarsening up to medium to coarse sand

Well Number: 984
Auger flight (feet): 5-10
Recovery length (inches): 53
Date: 10/27/89



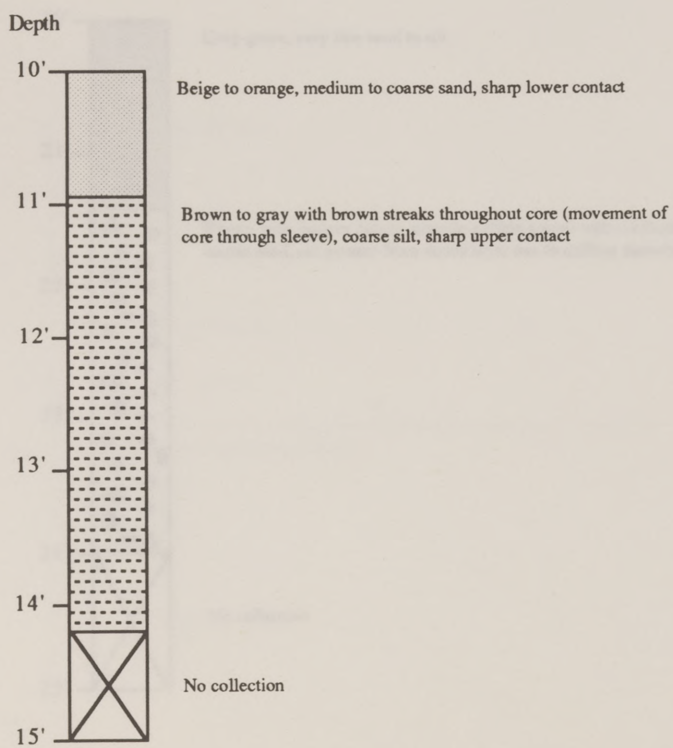
Brown-orange, medium to coarse sand

Brown to light gray, fine to medium sand, sharp upper contact

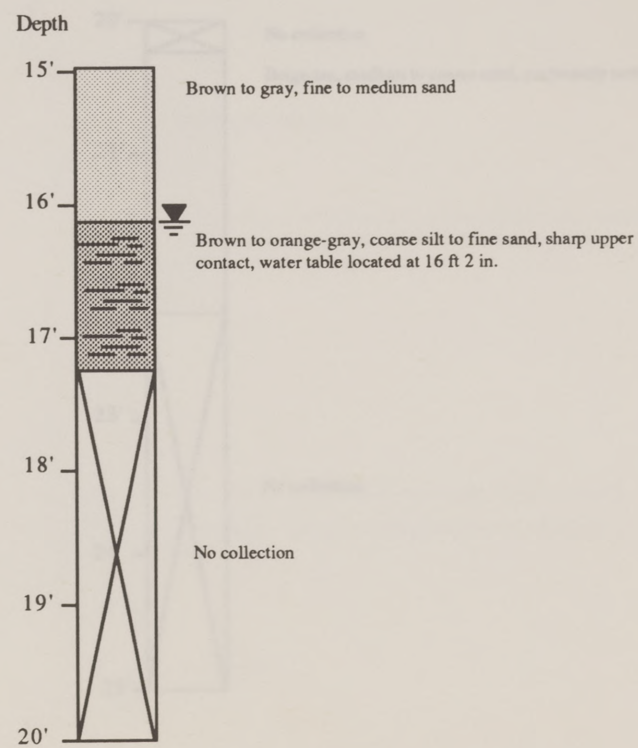
Orange-brown grading into beige, fine to medium sand coarsening up to medium sand with coarse sand

No collection

Well Number: 984
Auger flight (feet): 10-15
Recovery length (inches): 50.5
Date: 10/27/89

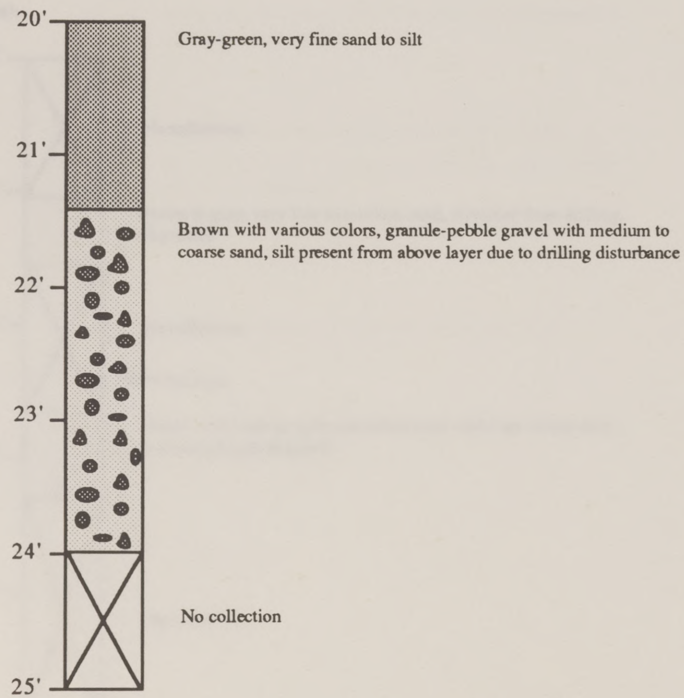


Well Number: 984
Auger flight (feet): 15-20
Recovery length (inches):27
Date: 10/28/89



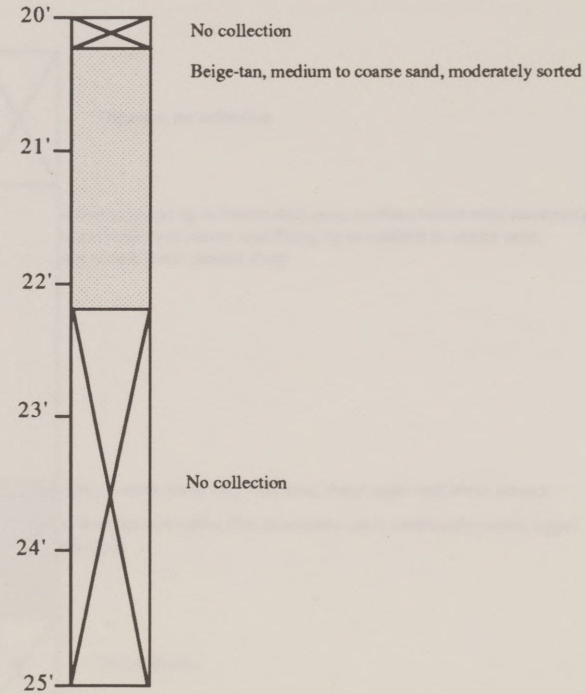
Well Number: 984
Auger flight (feet): 20-25
Recovery length (inches): 48
Date: 10/28/89

Depth

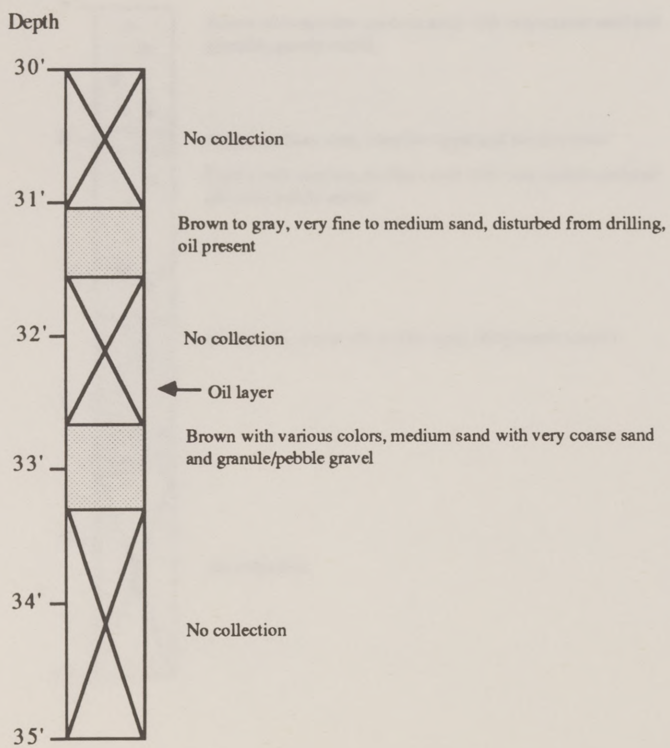


Well Number: 013
Auger flight (feet): 20-25
Recovery length (inches): 23.5
Date: 7/1/90

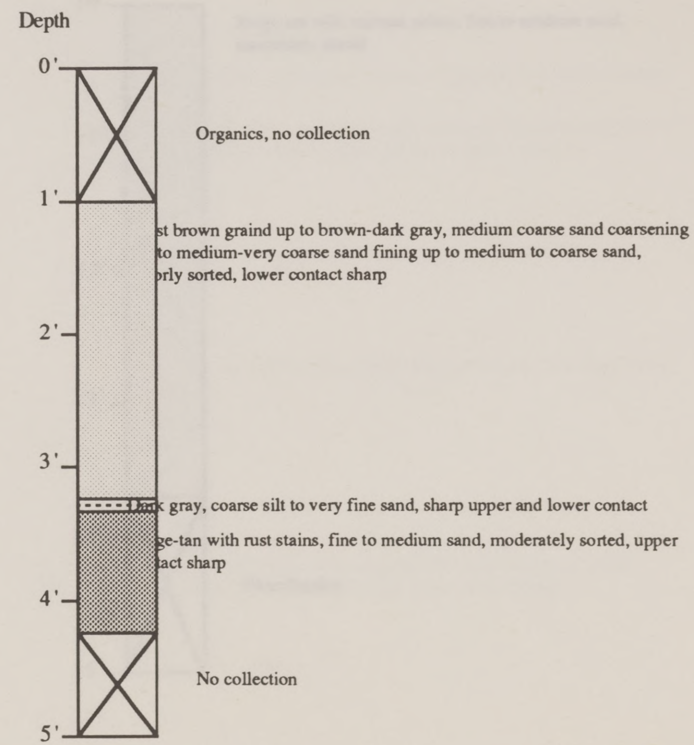
Depth



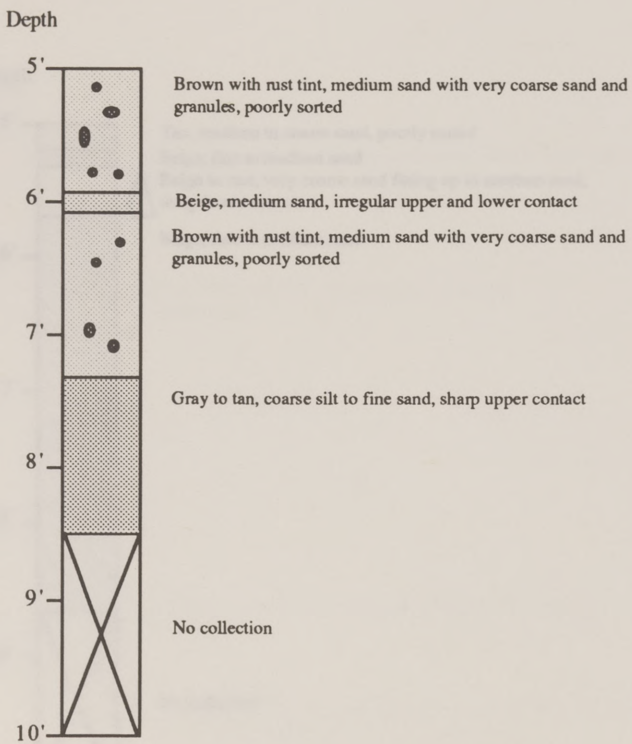
Well Number: 013
Auger flight (feet): 30-35
Recovery length (inches): 14
Date: 7/1/90



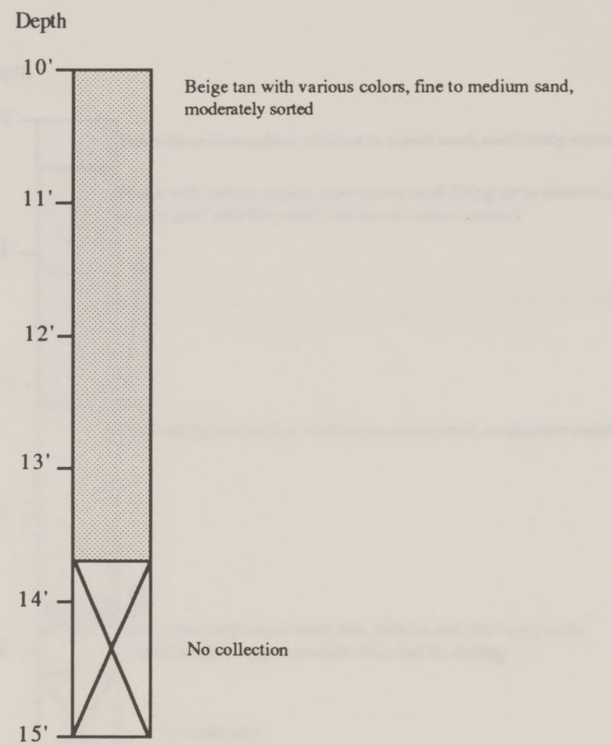
Well Number: 019
Auger flight (feet): 0-5
Recovery length (inches): 38.75
Date: 7/2/90



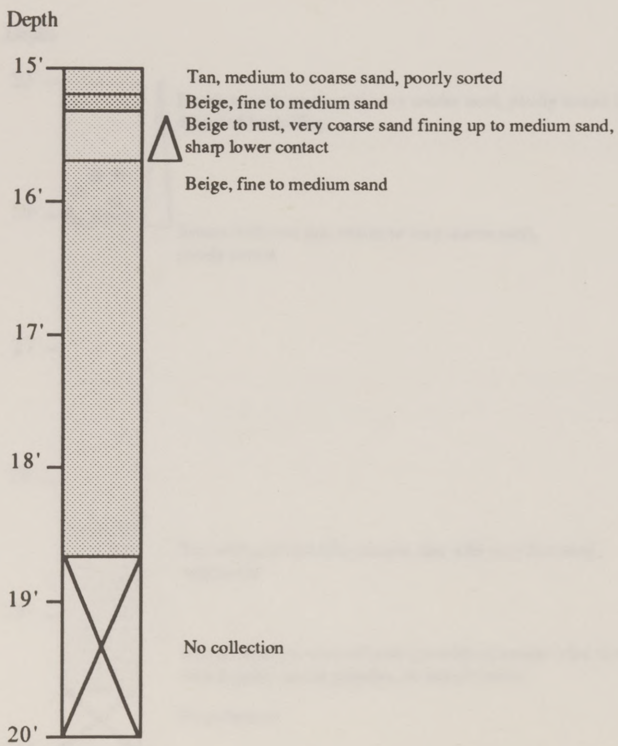
Well Number: 019
Auger flight (feet): 5-10
Recovery length (inches): 42.5
Date: 7/2/90



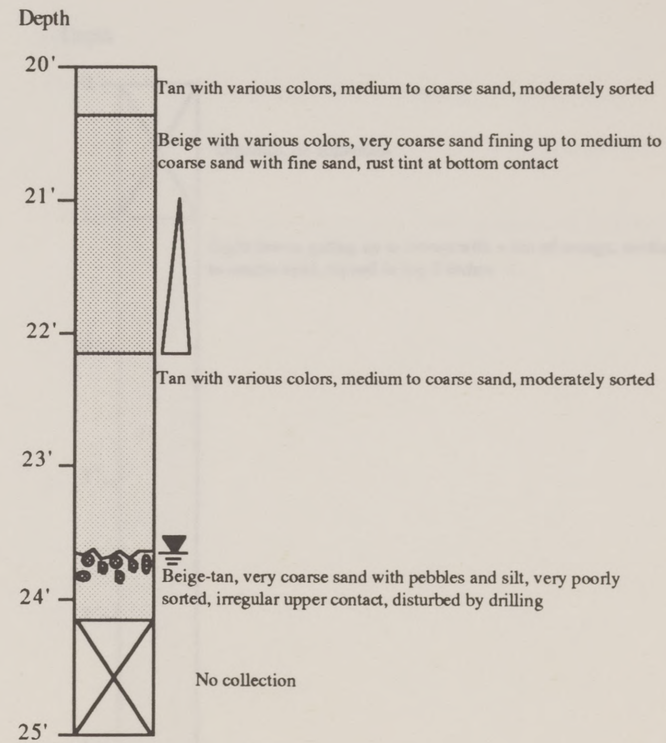
Well Number: 019
Auger flight (feet): 10-15
Recovery length (inches): 44
Date: 7/2/90



Well Number: 019
Auger flight (feet): 15-20
Recovery length (inches):44
Date: 7/2/90

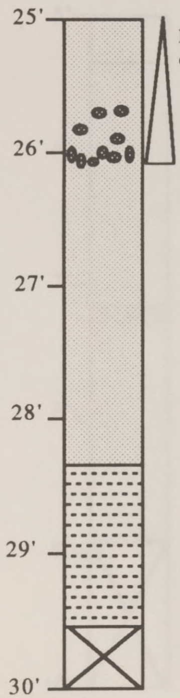


Well Number: 019
Auger flight (feet): 20-25
Recovery length (inches): 50
Date: 7/2/90



Well Number: 019
Auger flight (feet): 25-30
Recovery length (inches): 54.5
Date: 7/2/90

Depth



Brown to rust, medium to very coarse sand, poorly sorted, top 1 ft. disturbed by drilling

Brown with rust tint, coarse to very coarse sand, poorly sorted

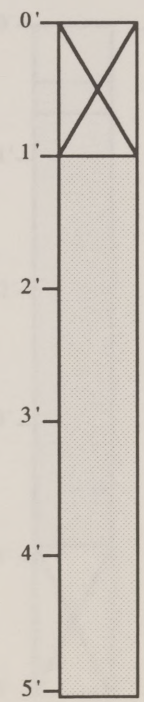
Tan with greenish tint, silt and clay with very fine sand, well sorted

Bottom of auger covered with greenish till matter, clay to very fine silt with angular coarse granules, no sample taken

No collection

Well Number: 020
Auger flight (feet): 0-5
Recovery length (inches): 48.5
Date: 7/2/90

Depth

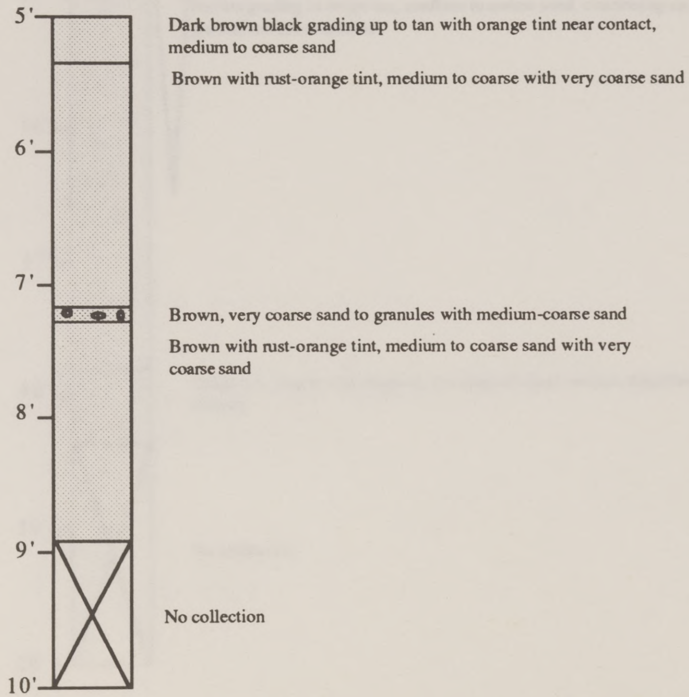


Organics, no collection

Light brown grding up to brown with a tint of orange, medium to coarse sand, topsoil in top 2 inches

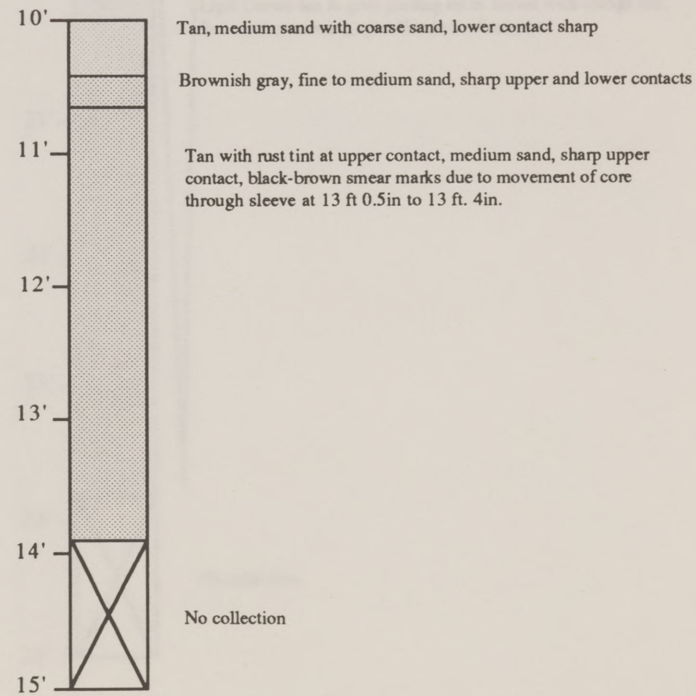
Well Number: 020
Auger flight (feet): 5-10
Recovery length (inches): 47.5
Date: 7/2/90

Depth

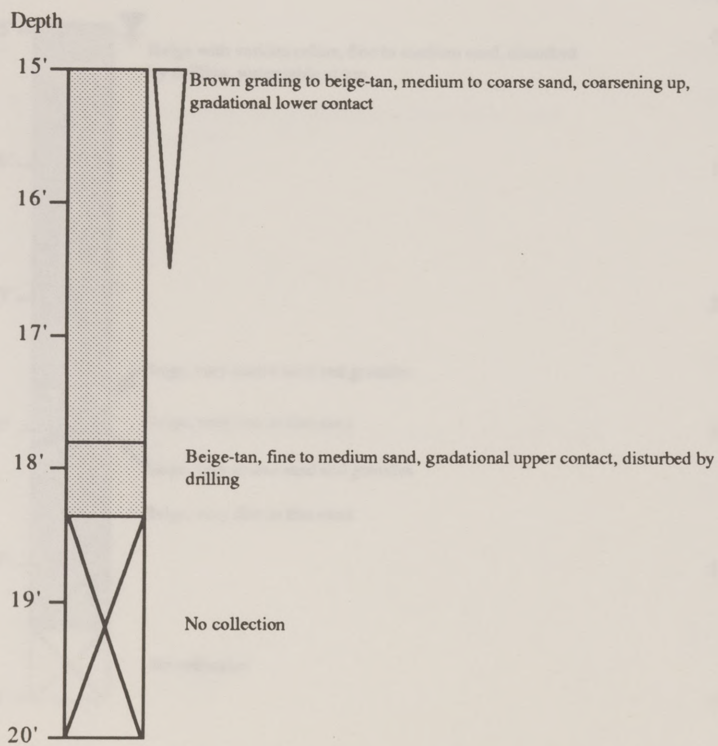


Well Number: 020
Auger flight (feet): 10-15
Recovery length (inches): 47
Date: 7/2/90

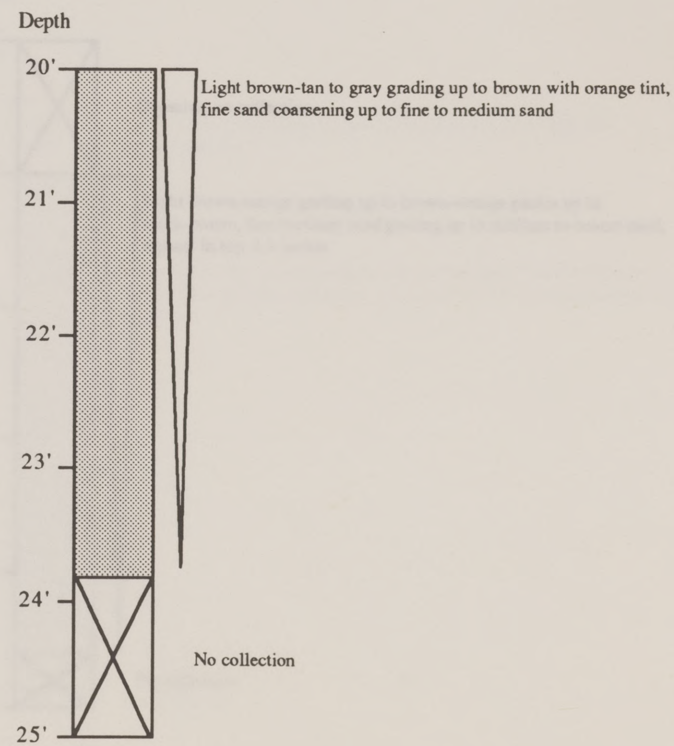
Depth



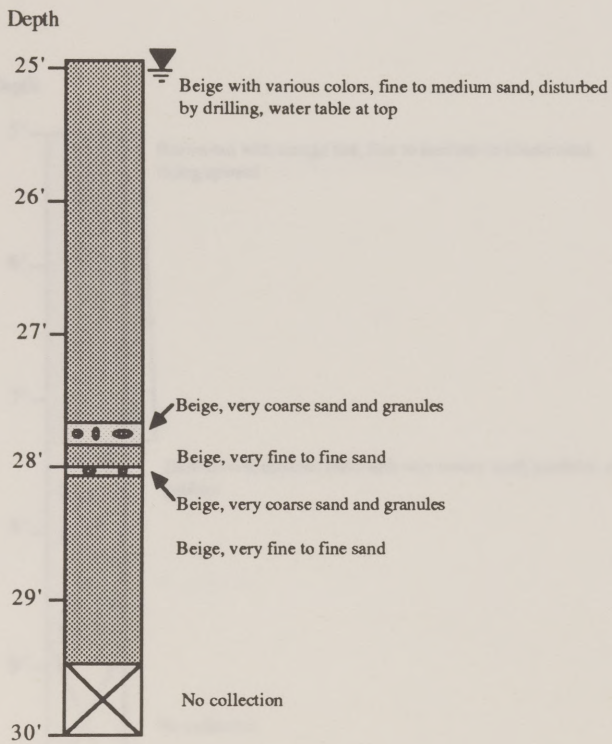
Well Number: 020
Auger flight (feet): 15-20
Recovery length (inches): 40.5
Date: 7/2/90



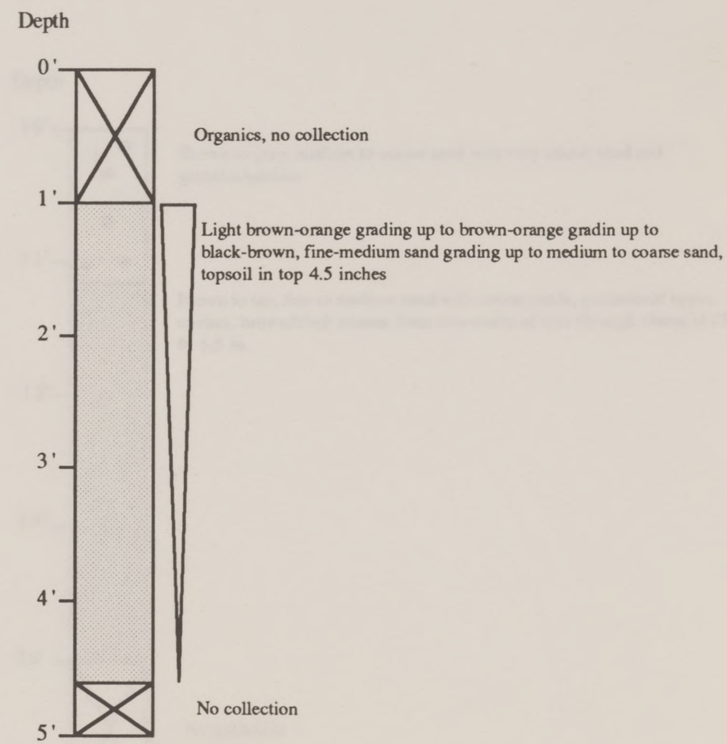
Well Number: 020
Auger flight (feet): 20-25
Recovery length (inches): 46
Date: 7/2/90



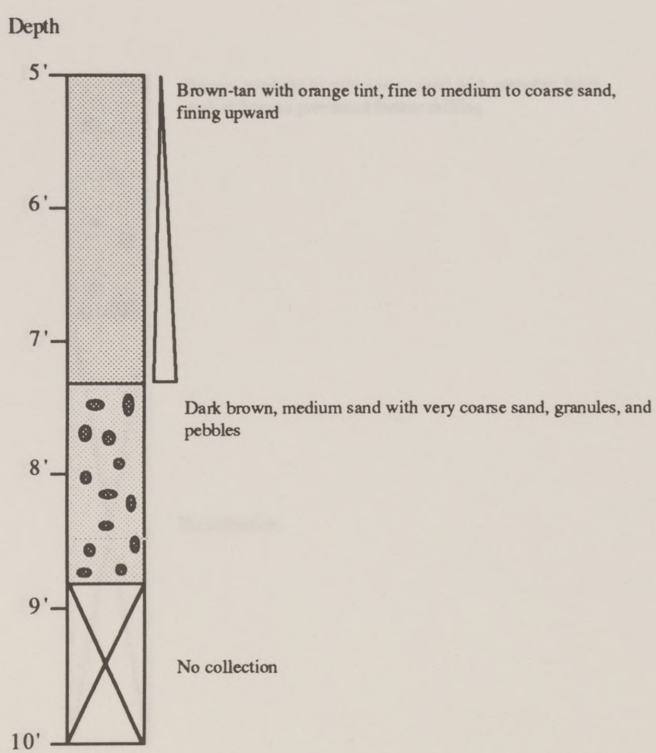
Well Number: 020
Auger flight (feet): 25-30
Recovery length (inches): 54
Date: 7/2/90



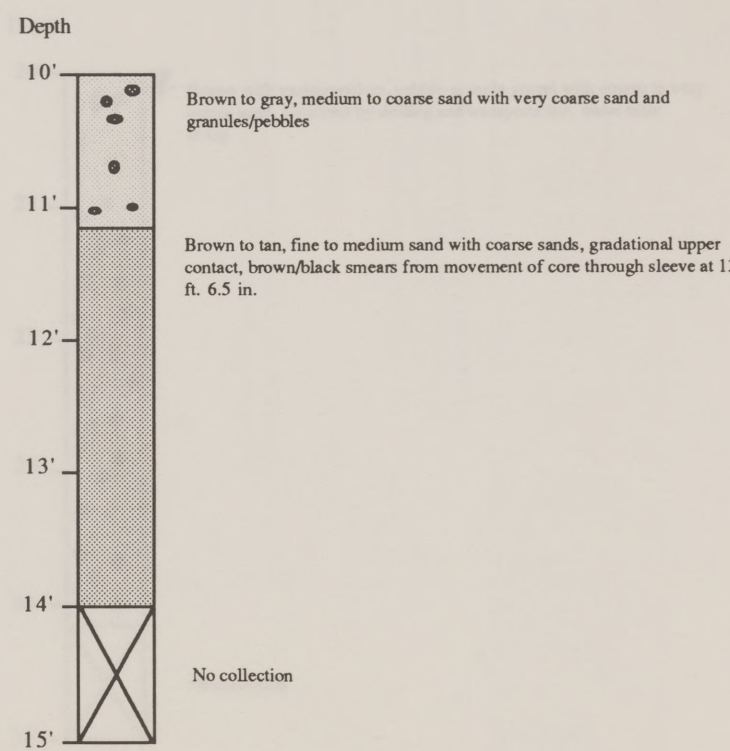
Well Number: 021
Auger flight (feet): 0-5
Recovery length (inches): 43.5
Date: 7/3/90



Well Number: 021
Auger flight (feet): 5-10
Recovery length (inches): 44.5
Date: 7/3/90

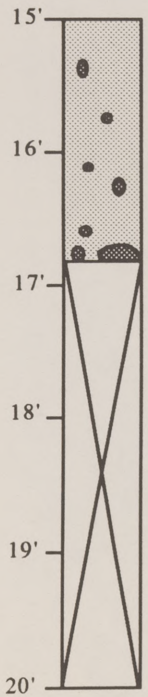


Well Number: 021
Auger flight (feet): 10-15
Recovey length (inches): 48
Date: 7/3/90



Well Number: 021
Auger flight (feet): 15-20
Recovery length (inches): 22
Date: 7/3/90

Depth

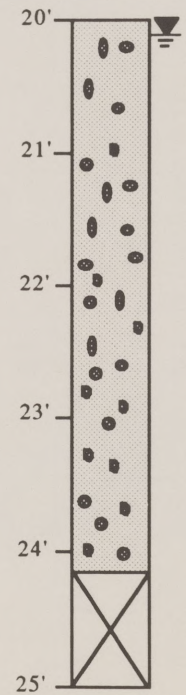


Brown, medium to very coarse sand with granules, large rock at bottom prevented further drilling

No collection

Well Number: 021
Auger flight (feet): 20-25
Recovery length (inches): 50
Date: 7/3/90

Depth



Brown with various colors, pebble-granule gravel with coarse to very coarse sand, disturbed by drilling and transportation, water table at top

No collection

Appendix A3 Water Table Elevation Records

Explanation

Well Number	LOCATION *a X (m)	Y (m)	Well Type Code *b	August 3-4, 1989 (CB) *c (m)	September 8, 1989 (CB) (m)	September 23, 1989 (DB) *d (m)	September 30, 1989 (DB) (m)	October 19-21, 1989 (CB) (m)	October 29-November 1, 1989 (SIB, CB) *e (m)	June 21-July 5, 1990 (SIB) (m)	August 8, 1990 (KN/DD) *f (m)	November 26, 1990 (KN) (m)	June 11-27, 1991 (EK) *g (m)

*a is the coordinates of the well location in an x-y coordinate system with (+)X to N52.3°E.
*b is the type of well. L is a local water table well and R is a regional water table well.
*c is the elevation of water table on the given date relative to mean sea level.
Measurements were taken by person listed in brackets. CB is Chad Bring.
*d DB is Don Boyce.
*e SIB is Sevin I. Bilir.
*f KN is Kevin Norman and DD is Doug Davidson.
*g EK is Elizabeth Klammer.

Blanks mean that no measurement was taken, the well had not been contructed yet, or the data is missing.
Italics mean that the water level was not used for generating water table maps due to error in elevation.

Well Number	LOCATION		Well Type Code	August 3-4, 1989 (CB)	September 8, 1989 (CB)	September 23, 1989 (DB)	September 30, 1989 (DB)	October 19-21, 1989 (CB)	October 29-November 1, 1989 (SIB, CB)	June 21-July 5, 1990 (SIB)	August 8, 1990 (KN/DD)	November 26, 1990 (KN)	June 11-27, 1991 (EK)
	X (m)	Y (m)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
303a	-48.18	-56.06	L						423.478	423.694	_423.418_		423.437
307a	-160.37	53.31	R						423.365	423.523	423.334		
310d	-97.89	-239.60	L	423.996	423.949	423.952		423.930	423.929	423.733		423.423	
311a	14.27	46.89	L	423.299		423.253	423.247	423.239	423.235	423.215	423.164	423.085	423.181
318a	1.13	0.38	L	423.435		423.387	_423.384_	423.383	423.376	423.348	423.351	423.215	423.532
401a	49.33	-485.01	R		424.240				424.229	424.193	424.159		424.173
402a	-195.14	-931.11	R		425.809				425.791	425.771	425.706		425.717
403a	-551.81	-2342.98	R		425.824				425.802	425.783			425.757
404a	-835.57	-980.38	R		426.043				426.017				
405a	-380.37	-623.21	R		425.687				425.669	_425.633_	425.604		425.614
406a	-798.13	-758.69	R		425.885				425.848	425.840	425.779		425.796
407a	-847.39	-646.32	R		425.781				425.746	425.717	425.684		
408a	-563.63	-426.16	R		425.489				425.455	425.389	425.388		
409a	139.87	-746.37	R						425.546	425.514	425.450		
410a	-798.13	-1214.40	R		426.190				426.159	426.221	426.060		
412a	-786.30	-373.63	R		_422.300_				_422.264_	_422.185_	_422.203_		_422.136_
413a	-983.36	-512.37	R		425.671				425.632	425.577	425.565		425.528
414a	73.00	-301.41	L		423.967				_423.316_	423.936	423.886		423.933
415a	-354.75	-118.26	R										
416a	7.13	20.93	L	423.369			423.317	423.315	423.319	423.278	423.244	423.153	423.245
417c	61.04	21.42	L	423.292			423.356	_423.254_	423.242	423.227	423.163		
418d	37.72	3.74	R	423.375			423.338	_423.338_	423.324	423.598	423.272		423.270
419c	16.05	-13.06	L	423.439			423.400	_423.393_	423.385	423.344	423.264	423.234	
420b	-3.57	-27.07	L							423.418	423.371	423.294	
421b	-26.71	-57.84	L							423.489			
502a	-786.30	-327.63	R		425.351				425.314	425.238	425.236		425.199
515a	26.39	74.84	L	423.220		423.176	_423.174_	_423.172_	423.158	423.145	423.109	423.020	423.120
516a	36.66	61.69	L	423.228			_433.919_	_423.152_	423.166	423.151	423.115	423.023	423.126
517a	9.14	67.22	L	423.424*			423.196	_423.195_	_422.822_	423.167	423.128		
518a	0.53	-1.11	L	423.434		423.391	_423.383_	423.378	423.382	423.348	423.327	423.217	423.239
519a	-9.23	1.84	L	423.436					423.369	423.346	423.318		
520a	-10.19	-11.16	L	423.474			423.422	423.416		423.384	423.340		
521a	-28.70	-29.49	L						423.485	423.464	423.422	_423.876_	
523a	-53.58	-115.69	L	_423.910_	_423.380_			_423.670_	_423.670_	_423.640_	_423.610_	_423.510_	_423.620_
527a	47.51	112.90	L	423.065		423.021	423.019	_423.015_	423.006	422.990	422.946	422.872	422.965
528a	23.49	107.79	L	423.125		423.081	423.076	423.071	423.065	423.052	423.010	422.922	423.236
529a	34.77	116.02	L	423.067		423.021	_423.014_	_423.009_	423.001	422.381*	422.945	422.860	422.947
530b	10.56	32.02	L	423.335		423.291	423.287	_423.283_	423.299	423.239	423.222	423.123	423.245
531a	3.57	9.12	L	423.396		423.361	_423.355_	423.353	423.350	423.323	423.291	423.198	423.291
532a	-3.64	-10.97	L	423.467		423.422	423.416	_423.416_	423.407	423.383	423.346	423.256	
533a	-7.96	-20.53	L						423.468	423.405	423.386	423.280	423.446
534b	-11.52	-31.16	L				_432.654_	_423.445_		423.422	423.372		
602a	260.85	-131.38	R						424.017	424.175	423.968		424.133
603a	-66.84	-162.71	L	423.808	423.758	423.911		423.744	423.737	423.714	423.686	423.581	423.688
604b	-41.39	-79.09	L		423.724	_424.117_		_423.589_	423.583	423.561	423.529		423.541
605a	29.47	96.94	L	423.139		423.093	423.090	423.076	423.079	423.063	423.027	422.936	_426.107*_
701a	-43.84	56.21	L	423.504			423.443	_423.447_	423.432	423.495	423.296		423.464
702a	-60.34	40.07	L	423.471			423.425	_423.428_	423.409	423.396	423.362		423.357
703a	-49.13	18.96	L	423.410			423.366	_423.383_	423.349	423.330	423.237		423.291
706a	-37.72	-3.91	L	423.464				_423.467_	423.405	423.381	423.359		423.340
707a	-54.13	-117.62	L	423.732	423.684	423.680		423.667	423.668	423.639	423.601	423.513	423.617
708a	-62.33	-143.77	L	423.796	423.745	_424.266_		_423.722_	423.725	423.694	423.668	423.561	_424.925*_
709a	-74.74	-184.01	L	423.878	423.827	_424.239_		_423.810_	423.804	423.784	423.748	423.650	423.763
710a	-68.86	-2.61	L	423.500			423.455	_423.572_	423.441	423.413	423.384		423.230
801a	24.44	62.92	L	423.244		423.200	423.198	_423.192_	423.181	423.166	423.127	423.035	423.136
807a	32.76	73.84	L						423.190	423.147	423.103		423.014
808a	22.36	71.24	L						423.170	423.152	423.120	423.026	
812a	-8.94	-84.23	L					_423.585_	423.577	423.555	423.532		
815b	-87.36	-145.60	L										
816b	-10.63	-171.46	L	423.851				_423.790_	423.781	423.818	423.732		423.748
912a	14.01	-53.32	L						423.463	423.450	423.408		
913a	-12.82	-71.80	L					_423.559_	423.549	423.527	423.488		
915a	160.13	-61.74	L						423.360	423.353	423.294		
916a	100.62	-79.58	L					423.417	423.420	423.411	423.363		

Well Number	LOCATION X (m)	LOCATION Y (m)	Well Type Code	August 3-4, 1989 (CB) (m)	September 8, 1989 (CB) (m)	September 23, 1989 (DB) (m)	September 30, 1989 (DB) (m)	October 19-21, 1989 (CB) (m)	October 29-November 1, 1989 (SIB, CB) (m)	June 21-July 5, 1990 (SIB) (m)	August 8, 1990 (KN/DD) (m)	November 26, 1990 (KN) (m)	June 11-27, 1991 (EK) (m)
919a	154.92	-29.71	L						423.284	423.281	423.142		
925a	75.20	184.60	L	422.870		422.830	422.830	_422.820_	_422.810_	422.628	422.690	422.680	
926a	230.72	145.65	L										
927a	225.87	-55.13	R							423.286	423.225		
954a	43.75	123.09	L	422.998		422.952	422.948	_422.950_	422.937	422.926	422.879	422.792	_424.007*_
955b	54.53	170.26	L	422.819		422.749	_422.744_	_422.743_	422.734	422.679	422.656	422.571	
956a	-24.48	-164.84	L					423.742	423.737	423.713	423.676		423.690
957a	-13.20	-219.36	L						423.749	423.756	423.771		424.007
958a	42.81	-107.31	L						_423.589_				
982a	90.70	-77.22	L							423.479	423.431		
983a	147.77	-263.45	L							423.918	423.581		423.904
984a	45.77	-163.68	L							423.696	423.588		423.693
001a	52.53	-25.37	L							423.350	423.270		423.320
002a	92.82	-272.15	L							423.908	423.816		423.884
003a	96.73	-266.04	L							424.066	423.617		424.007
004a	85.73	-284.93	L							423.901	423.821		423.882
005a	62.34	-204.79	L							423.789	423.688		423.767
006a	51.26	-203.02	L							423.778	423.694		423.759
007a	74.04	-207.44	L							423.948			424.055
008a	141.11	-263.10	L							423.918			423.897
009a	127.30	-261.83	L							423.972			423.998
010a	152.26	-263.26	L							423.908			423.899
011a	112.42	-275.04	L							423.956	423.643		
012a	73.04	-230.04	L							423.997			
019a	-73.40	64.82	L							423.407	423.355		423.470
020	87.97	-22.96	L							423.360	423.290		_424.54*_
021	125.25	-333.53	L							424.012	423.940		423.979

Staff Location													
Wetland	113.32	-197.38	L							424.043	423.540	423.707	424.024

Appendix A4 Particle-Size Analysis

Well: 702c Auger flight (ft.): 0-5 Depth range (ft.): 1' 2" - 3' 1"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	446.9	427.2	19.7	19.7	98.76
2	-1	455.8	431.5	24.3	44	97.24
1	0	523.9	398.4	125.5	169.5	89.37
0.5	1	911	313.1	597.9	767.4	51.85
0.25	2	942	317.3	624.7	1392.1	12.66
0.15	2.75	398.5	334.6	63.9	1456	8.65
0.075	3.75	299.5	238.1	61.4	1517.4	4.8
0.045	4.5	255.6	231.5	24.1	1541.5	3.29
pan	pan	368.4	316	52.4	1593.9	0
			Total	1593.9		

Percent error: 0.1 d10* : 0.23

Well: 702c Auger flight (ft.): 0-5 Depth range (ft.): 3' 1.5" - 4' 8"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	462.8	427	35.8	35.8	97.45
2	-1	443.5	430.6	12.9	48.7	96.53
1	0	441.5	398.9	42.6	91.3	93.49
0.5	1	569.3	313	256.3	347.6	75.21
0.25	2	1190.1	316.5	873.6	1221.2	12.91
0.15	2.75	453.5	334.2	119.3	1340.5	4.41
0.075	3.75	284.6	237.7	46.9	1387.4	1.06
0.045	4.5	238.7	231.3	7.4	1394.8	0.53
pan	pan	323.5	316	7.5	1402.3	0
			Total	1402.3		

Percent error: 0.55 d10 : 0.22

Well: 702c Auger flight (ft.): 5-10 Depth range (ft.): 5' 1" - 6' 1.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	420.2	420.2	0	0	100
2	-1	354.2	353.9	0.3	0.3	99.97
1	0	314.3	313.1	1.2	1.5	99.83
0.5	1	336.9	299.9	37	38.5	95.73
0.25	2	959.9	316.8	643.1	681.6	24.39
0.125	3	595.3	419.8	175.5	857.1	4.93
0.0625	4	431	398.7	32.3	889.4	1.34
pan	pan	481.4	469.3	12.1	901.5	0
			Total	901.5		

Percent error: 0.42 d10 : 0.18

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 10' 1" - 10' 9"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	459.5	425.8	33.7	33.7	94.8
2	-1	452.3	427.6	24.7	58.4	90.98
1	0	460.5	393.5	67	125.4	80.64
0.5	1	480.1	312.2	167.9	293.3	54.72
0.25	2	589.5	390.4	199.1	492.4	23.99
0.125	3	431.5	333.8	97.7	590.1	8.91
0.0625	4	268.1	249.1	19	609.1	5.97
pan	pan	354.9	316.2	38.7	647.8	0
			Total	647.8		

Percent error: 0.64 d10 : 0.12

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 10' 9" - 11' 3"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.7	402.5	0.2	0.2	99.95
2	-1	361.3	356.8	4.5	4.7	98.78
1	0	345.4	318.1	27.3	32	91.71
0.5	1	348.4	299.7	48.7	80.7	79.09
0.25	2	312.7	277	35.7	116.4	69.84
0.106	3.25	302.7	239.6	63.1	179.5	53.5
0.053	4.25	442.9	239	203.9	383.4	0.67
0.038	4.75	230.4	228.9	1.5	384.9	0.28
pan	pan	470.5	469.4	1.1	386	0
			Total	386		

Percent error: 0.28 d10 : 0.06

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 11' 7.5" - 12'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	449.3	425.8	23.5	23.5	91.98
2	-1	442.9	427.6	15.3	38.8	86.77
1	0	435.5	393.4	42.1	80.9	72.41
0.5	1	425.5	312.3	113.2	194.1	33.8
0.25	2	426.9	390.5	36.4	230.5	21.38
0.125	3	361.9	333.8	28.1	258.6	11.8
0.0625	4	259.6	248.8	10.8	269.4	8.12
pan	pan	340	316.2	23.8	293.2	0
			Total	293.2		

Percent error: 0 d10 : 0.105

* *d10, effective grain size is value where 10% of particles are finer*

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 12' - 12' 5.25"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	469.2	402.4	66.8	66.8	84.88
2	-1	400.1	354.1	46	112.8	74.47
1	0	368.6	312.7	55.9	168.7	61.82
0.5	1	405.9	298.8	107.1	275.8	37.59
0.25	2	417.2	315.4	101.8	377.6	14.55
0.125	3	465.5	430.7	34.8	412.4	6.68
0.0625	4	407.8	398.5	9.3	421.7	4.57
pan	pan	489.5	469.3	20.2	441.9	0
			Total	441.9		

Percent error: -0.2 d10 : 0.2

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 12' 5.25" - 13'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	428.2	402.3	25.9	25.9	94.95
2	-1	374.6	354	20.6	46.5	90.93
1	0	349.3	312.7	36.6	83.1	83.8
0.5	1	380.4	298.6	81.8	164.9	67.85
0.25	2	494.7	315.2	179.5	344.4	32.85
0.125	3	536.5	430.7	105.8	450.2	12.22
0.0625	4	416.4	398.6	17.8	468	8.75
pan	pan	514.2	469.3	44.9	512.9	0
			Total	512.9		

Percent error: 0.14 d10 : 0.1

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 13' - 13' 6"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	457.9	402.4	55.5	55.5	89.14
2	-1	401.2	354.2	47	102.5	79.94
1	0	384.7	312.7	72	174.5	65.84
0.5	1	404.6	298.5	106.1	280.6	45.08
0.25	2	429.6	315.1	114.5	395.1	22.67
0.125	3	501.1	430.6	70.5	465.6	8.87
0.0625	4	408	398.5	9.5	475.1	7.01
pan	pan	505	469.2	35.8	510.9	0
			Total	510.9		

Percent error: 0 d10 : 0.12

Well: 702c Auger flight (ft.): 10-15 Depth range (ft.): 13' 6" - 14' 4.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	469.2	425.8	43.4	43.4	93.29
2	-1	443.8	427.7	16.1	59.5	90.8
1	0	446	393.9	52.1	111.6	82.75
0.5	1	464.9	312.9	152	263.6	59.26
0.25	2	660.2	391.2	269	532.6	17.68
0.125	3	427.7	333.8	93.9	626.5	3.17
0.0625	4	254.5	248.9	5.6	632.1	2.3
pan	pan	331.1	316.2	14.9	647	0
			Total	647		

Percent error: 0.22 d10 : 0.205

Well: 702c Auger flight (ft.): 15-20 Depth range (ft.): 15' 2" - 15' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
2	-1	441.2	428.6	12.6	12.6	98.15
1	0	417.3	395.3	22	34.6	94.92
0.5	1	373.1	313.6	59.5	94.1	86.17
0.25	2	578.1	427.3	150.8	244.9	64.01
0.106	3.25	639.4	321.9	317.5	562.4	17.35
0.0625	4	322.2	252.9	69.3	631.7	7.17
0.045	4.5	294.6	292.4	2.2	633.9	6.85
pan	pan	362.7	316.1	46.6	680.5	0
			Total	680.5		

Percent error: 0.48 d10 : 0.12

Well: 702c Auger flight (ft.): 15-20 Depth range (ft.): 16' 0.5" - 18'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
1	0	397.9	395	2.9	2.9	99.83
0.5	1	344.6	313.5	31.1	34	97.97
0.25	2	1349.2	430.3	918.9	952.9	43.16
0.106	3.25	897.1	322.9	574.2	1527.1	8.91
0.0625	4	313.2	252.7	60.5	1587.6	5.3
0.045	4.5	275	231.3	43.7	1631.3	2.69
0.037		244.5	228.7	15.8	1647.1	1.75
pan	pan	345.4	316.1	29.3	1676.4	0
			Total	1676.4		

Percent error: 1.48 d10 : 0.11

Well: 702c Auger flight (ft.): 15-20 Depth range (ft.): 18' - 19' 6"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426.4	426.4	0	0	100
2	-1	429.2	428.9	0.3	0.3	99.98
1	0	396.3	395.8	0.5	0.8	99.94
0.5	1	335.2	313.9	21.3	22.1	98.41
0.25	2	860.9	392.5	468.4	490.5	64.81
0.125	3	1055.6	334.2	721.4	1211.9	13.06
0.0625	4	301.1	249.2	51.9	1263.8	9.34
pan	pan	446.3	316.1	130.2	1394	0
			Total	1394		

Percent error: 0.16 d10 : 0.11

Well: 702c Auger flight (ft.): 20-25 Depth range (ft.): 22' 0.25" - 22' 11.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	430.1	425.8	4.3	4.3	99.5
2	-1	429.2	427.6	1.6	5.9	99.32
1	0	401.3	393.8	7.5	13.4	98.45
0.5	1	592.5	312.7	279.8	293.2	66.05
0.25	2	798.9	391.2	407.7	700.9	18.83
0.125	3	478.8	333.8	145	845.9	2.04
0.0625	4	259.9	248.9	11	856.9	0.76
pan	pan	322.8	316.2	6.6	863.5	0
			Total	863.5		

Percent error: 0.22 d10 : 0.2

Well: 702c Auger flight (ft.): 20-25 Depth range (ft.): 20' 1.5" - 20' 11.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	431.5	425.8	5.7	5.7	99.29
2	-1	433.8	427.5	6.3	12	98.51
1	0	413.9	393.3	20.6	32.6	95.96
0.5	1	439.2	312.9	126.3	158.9	80.3
0.25	2	787.9	390.9	397	555.9	31.09
0.125	3	546.1	333.9	212.2	768.1	4.78
0.0625	4	268.8	249.1	19.7	787.8	2.34
pan	pan	335.1	316.2	18.9	806.7	0
			Total	806.7		

Percent error: 0.25 d10 : 0.13

Well: 702c Auger flight (ft.): 20-25 Depth range (ft.): 23' 0.25" - 23' 11.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.2	402.2	0	0	100
2	-1	354.1	353.9	0.2	0.2	99.98
1	0	312.9	312.6	0.3	0.5	99.94
0.5	1	312.8	298.4	14.4	14.9	98.24
0.25	2	958.7	315.4	643.3	658.2	22.47
0.125	3	602.9	430.4	172.5	830.7	2.16
0.0625	4	408.1	398.5	9.6	840.3	1.02
pan	pan	478	469.3	8.7	849	0
			Total	849		

Percent error: 0.09 d10 : 0.205

Well: 702c Auger flight (ft.): 20-25 Depth range (ft.): 21' 0.25" - 21' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.4	402.4	0	0	100
2	-1	354.2	354	0.2	0.2	99.98
1	0	314.9	312.6	2.3	2.5	99.71
0.5	1	339.4	299.1	40.3	42.8	95.04
0.25	2	1037.8	316.8	721	763.8	11.56
0.125	3	521.3	430.9	90.4	854.2	1.09
0.0625	4	403.9	398.5	5.4	859.6	0.46
pan	pan	473.3	469.3	4	863.6	0
			Total	863.6		

Percent error: 0.44 d10 : 0.22

Well: 702c Auger flight (ft.): 20-25 Depth range (ft.): 24' 0.25" - 24' 5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	433.5	425.7	7.8	7.8	97.81
2	-1	432.8	427.5	5.3	13.1	96.33
1	0	398.2	393.7	4.5	17.6	95.07
0.5	1	346.1	312.4	33.7	51.3	85.62
0.25	2	623.1	391.2	231.9	283.2	20.63
0.125	3	401.6	333.8	67.8	351	1.63
0.0625	4	252	248.8	3.2	354.2	0.73
pan	pan	318.8	316.2	2.6	356.8	0
			Total	356.8		

Percent error: 0.08 d10 : 0.205

Well: 958D Auger flight (ft.): 10-15 Depth range (ft.): 12' - 14'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	586	402.6	183.4	183.4	72.3
2	-1	408.9	354.5	54.4	237.8	64.09
1	0	380.1	315.6	64.5	302.3	54.35
0.5	1	385.6	300.5	85.1	387.4	41.5
0.25	2	422.5	352.1	70.4	457.8	30.87
0.125	3	507.3	431.1	76.2	534	19.36
0.0625	4	401.4	399.2	2.2	536.2	19.03
pan	pan	595.4	469.4	126	662.2	0
			Total	662.2		

Percent error: 0.15

Well: 981 Auger flight (ft.): 0-5 Depth range (ft.): 1' - 2' 7"

Sieve Opening (mm)	(phi)	Sieve (gm)	Weight retained (gm)	Weight Retained (gms)	Cumulative Percent Finer (%)	
4	-2	533.9	427.1	106.8	106.8	92.5
2	-1	475.3	431.4	43.9	150.7	89.41
1	0	504.9	399.8	105.1	255.8	82.03
0.5	1	674.9	313	361.9	617.7	56.6
0.25	2	957.2	316.7	640.5	1258.2	11.59
0.15	2.75	412.3	334.2	78.1	1336.3	6.11
0.075	3.75	298.1	237.9	60.2	1396.5	1.88
0.045	4.5	242.8	231.4	11.4	1407.9	1.08
pan	pan	331.4	316.1	15.3	1423.2	0
		4430.8	3007.6	1423.2		

Percent error: 0.15 d10 : 0.21

Well: 980 Auger flight (ft.): 0-5 Depth range (ft.): 2' 5.25" - 3' 3.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	454.8	403	51.8	51.8	93.52
2	-1	395.7	354.8	40.9	92.7	88.41
1	0	384.8	315.5	69.3	162	79.74
0.5	1	500.4	300.4	200	362	54.73
0.25	2	629.4	351	278.4	640.4	19.91
0.125	3	541.1	431.1	110	750.4	6.15
0.0625	4	418.1	398.7	19.4	769.8	3.73
pan	pan	499.1	469.3	29.8	799.6	0
			Total	799.6		

Percent error: -0.1 d10 : 0.16

Well: 982 Auger flight (ft.): 0-5 Depth range (ft.): 1' 2.5" - 2'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	411.9	2.8	409.1	409.1	60.66
2	-1	359.9	354.5	5.4	414.5	60.14
1	0	343.2	315.2	28	442.5	57.44
0.5	1	429.3	300.9	128.4	570.9	45.1
0.25	2	587	316.3	270.7	841.6	19.06
0.125	3	567.5	430.9	136.6	978.2	5.92
0.0625	4	428.9	398.6	30.3	1008.5	3.01
pan	pan	500.6	469.3	31.3	1039.8	0
			Total	1039.8		

Percent error: 0.05 d10 : 0.16

Well: 980 Auger flight (ft.): 0-5 Depth range (ft.): 3' 4" - 4' 8"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	499.3	402.7	96.6	96.6	92.14
2	-1	422.7	356.4	66.3	162.9	86.74
1	0	424.7	318.5	106.2	269.1	78.09
0.5	1	608.4	301.2	307.2	576.3	53.09
0.25	2	800.3	352.3	448	1024.3	16.62
0.125	3	561.5	431.6	129.9	1154.2	6.04
0.0625	4	436.1	398.9	37.2	1191.4	3.01
pan	pan	506.2	469.2	37	1228.4	0
			Total	1228.4		

Percent error: 0.25 d10 : 0.2

Well: 982 Auger flight (ft.): 0-5 Depth range (ft.): 2' 0.5" - 2' 11.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	428.4	402.3	26.1	26.1	97.15
2	-1	383.5	354.2	29.3	55.4	93.95
1	0	398.2	313.4	84.8	140.2	84.69
0.5	1	573	300.1	272.9	413.1	54.9
0.25	2	670.6	316.3	354.3	767.4	16.21
0.125	3	548.6	430.9	117.7	885.1	3.36
0.0625	4	423	398.7	24.3	909.4	0.71
pan	pan	475.6	469.1	6.5	915.9	0
			Total	915.9		

Percent error: 0.25 d10 : 0.2

Well: 982 Auger flight (ft.): 0-5 Depth range (ft.): 3' 0.25" - 3' 10"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	456.9	425.9	31	31	95.68
2	-1	465.4	428.2	37.2	68.2	90.51
1	0	494.3	395	99.3	167.5	76.68
0.5	1	527.1	312.6	214.5	382	46.82
0.25	2	637.6	390.5	247.1	629.1	12.42
0.125	3	418.6	333.9	84.7	713.8	0.63
0.0625	4	252.1	249	3.1	716.9	0.19
pan	pan	317.6	316.2	1.4	718.3	0
			Total	718.3		

Percent error: 0.22 d10 : 0.22

Well: 982 Auger flight (ft.): 5-10 Depth range (ft.): 5' 1.5" - 5' 11.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	477.6	403	74.6	74.6	90.92
2	-1	439.7	354.5	85.2	159.8	80.54
1	0	511.1	315.4	195.7	355.5	56.71
0.5	1	560.7	301.2	259.5	615	25.11
0.25	2	473.8	316.2	157.6	772.6	5.92
0.125	3	456.5	430.7	25.8	798.4	2.78
0.0625	4	402.6	398.6	4	802.4	2.29
pan	pan	488.1	469.3	18.8	821.2	0
			Total	821.2		

Percent error: 0.22 d10 : 0.305

Well: 982 Auger flight (ft.): 5-10 Depth range (ft.): 6' 0.25" - 6' 3"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	413.3	402.4	10.9	10.9	94.77
2	-1	368.6	356.6	12	22.9	89.02
1	0	345.7	317.7	28	50.9	75.6
0.5	1	342.4	299.2	43.2	94.1	54.89
0.25	2	302	276.6	25.4	119.5	42.71
0.106	3.25	273.5	237.7	35.8	155.3	25.55
0.053	4.25	259.1	238.5	20.6	175.9	15.68
0.038	4.75	240.5	228.7	11.8	187.7	10.02
pan	pan	490.1	469.2	20.9	208.6	0
			Total	208.6		

Percent error: -0.3 d10 : 0.038

Well: 982 Auger flight (ft.): 5-10 Depth range (ft.): 6' 3.5" - 8'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	468.1	403.3	64.8	64.8	95.83
2	-1	440.6	357.4	83.2	148	90.48
1	0	504	320.3	183.7	331.7	78.66
0.5	1	875.8	300.8	575	906.7	41.66
0.25	2	790.9	352.2	438.7	1345.4	13.43
0.125	3	571	431.5	139.5	1484.9	4.45
0.0625	4	435.4	399.2	36.2	1521.1	2.12
pan	pan	502.4	469.4	33	1554.1	0
			Total	1554.1		

Percent error: 0.08 d10 : 0.16

Well: 982 Auger flight (ft.): 5-10 Depth range (ft.): 8' 0.5" - 9'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	444.8	403.1	41.7	41.7	95.4
2	-1	388.8	357	31.8	73.5	91.88
1	0	371.8	319.8	52	125.5	86.14
0.5	1	415.5	301.7	113.8	239.3	73.58
0.25	2	798.1	352.6	445.5	684.8	24.39
0.125	3	593.5	431.8	161.7	846.5	6.54
0.0625	4	434.8	399.2	35.6	882.1	2.61
pan	pan	493	469.4	23.6	905.7	0
			Total	905.7		

Percent error: 0.18 d10 : 0.22

Well: 982 Auger flight (ft.): 10-15 Depth range (ft.): 10' 1.5" - 11' 1.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	425.7	425.7	0	0	100
2	-1	428.1	427.6	0.5	0.5	99.94
1	0	394.6	393.6	1	1.5	99.83
0.5	1	316.8	312.5	4.3	5.8	99.33
0.25	2	470.9	391	79.9	85.7	90.15
0.125	3	930.7	334.2	596.5	682.2	21.6
0.0625	4	343.9	248.8	95.1	777.3	10.68
pan	pan	409.1	316.2	92.9	870.2	0
			Total	870.2		

Percent error: 0 d10 : 0.062

Well: 982 Auger flight (ft.): 10-15 Depth range (ft.): 11' 2" - 12' 8"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	407.4	402.4	5	5	99.63
2	-1	358.1	355.9	2.2	7.2	99.47
1	0	321.5	317.5	4	11.2	99.18
0.5	1	384.9	301.2	83.7	94.9	93.01
0.25	2	790	277	513	607.9	55.23
0.15	2.75	859.9	333.7	526.2	1134.1	16.48
0.075	3.75	512.2	320.4	191.8	1325.9	2.36
0.045	4.5	314.4	303.4	11	1336.9	1.55
pan	pan	490.3	469.3	21	1357.9	0
			Total	1357.9		

Percent error: 0.08 d10 : 0.1

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 15' 0.75" - 15' 7.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.5	402.2	0.3	0.3	99.94
2	-1	354.9	354.1	0.8	1.1	99.78
1	0	314.3	312.7	1.6	2.7	99.46
0.5	1	313.3	298.7	14.6	17.3	96.55
0.25	2	675.9	315.9	360	377.3	24.81
0.125	3	540.6	430.7	109.9	487.2	2.91
0.0625	4	407.4	398.5	8.9	496.1	1.14
pan	pan	474.9	469.2	5.7	501.8	0
			Total	1228.4		

Percent error: 0.04 d10 : 0.2

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 15' 8" - 16' 3.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.2	402.2	0	0	100
2	-1	354.7	354.1	0.6	0.6	99.89
1	0	314.6	313.3	1.3	1.9	99.66
0.5	1	322.1	299.9	22.2	24.1	95.71
0.25	2	727.8	316.3	411.5	435.6	22.48
0.125	3	542.4	430.8	111.6	547.2	2.62
0.0625	4	405.8	398.6	7.2	554.4	1.33
pan	pan	476.8	469.3	7.5	561.9	0
			Total	561.9		

Percent error: -0.1 d10 : 0.2

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 16' 4" - 16' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.2	402.2	0	0	100
2	-1	354.1	353.9	0.2	0.2	99.96
1	0	314.9	312.6	2.3	2.5	99.51
0.5	1	334.4	299.3	35.1	37.6	92.63
0.25	2	660.1	316	344.1	381.7	25.14
0.125	3	542.9	430.8	112.1	493.8	3.16
0.0625	4	408.6	398.6	10	503.8	1.2
pan	pan	475.4	469.3	6.1	509.9	0
			Total	509.9		

Percent error: -0.1 d10 : 0.18

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 17' 0.25" - 17' 7.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	402.3	402.3	0	0	100
2	-1	354.2	354	0.2	0.2	99.96
1	0	313	312.7	0.3	0.5	99.9
0.5	1	326	298.6	27.4	27.9	94.48
0.25	2	579.5	316.1	263.4	291.3	42.41
0.125	3	612	430.8	181.2	472.5	6.58
0.0625	4	413.7	398.6	15.1	487.6	3.6
pan	pan	487.5	469.3	18.2	505.8	0
			Total	505.8		

Percent error: 0.08 d10 : 0.12

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 17' 8" - 18' 3.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	418.4	402.2	16.2	16.2	97.27
2	-1	359	354	5	21.2	96.43
1	0	316.1	312.7	3.4	24.6	95.86
0.5	1	401.2	299.9	101.3	125.9	78.8
0.25	2	703.6	315.9	387.7	513.6	13.51
0.125	3	492.9	430.7	62.2	575.8	3.03
0.0625	4	404.9	398.5	6.4	582.2	1.95
pan	pan	480.8	469.2	11.6	593.8	0
			Total	593.8		

Percent error: 0.1 d10 : 0.205

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 18' 4" - 18' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	413.3	402.2	11.1	11.1	98.17
2	-1	361.5	354	7.5	18.6	96.94
1	0	336.2	312.6	23.6	42.2	93.05
0.5	1	470.7	300	170.7	212.9	64.96
0.25	2	615.7	315.8	299.9	512.8	15.6
0.125	3	487.8	430.7	57.1	569.9	6.2
0.0625	4	430	404.9	25.1	595	2.07
pan	pan	481.9	469.3	12.6	607.6	0
			Total	607.6		

Percent error: 0.27 d10 : 0.18

Well: 982 Auger flight (ft.): 15-20 Depth range (ft.): 19' 0.25" - 19' 7.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	420.3	402.3	18	18	96.78
2	-1	365.5	354	11.5	29.5	94.73
1	0	334.5	312.7	21.8	51.3	90.84
0.5	1	393.5	298.9	94.6	145.9	73.94
0.25	2	636.8	315.8	321	466.9	16.6
0.125	3	501.2	430.7	70.5	537.4	4
0.0625	4	408.4	398.5	9.9	547.3	2.23
pan	pan	481.7	469.2	12.5	559.8	0
			Total	559.8		

Percent error: 0.11 d10 : 0.205

Well: 983 Auger flight (ft.): 0-5 Depth range (ft.): 1' 7" - 3'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	462.4	402.4	60	60	95.17
2	-1	367.6	356.2	11.4	71.4	94.26
1	0	341.5	317	24.5	95.9	92.29
0.5	1	508.7	300.7	208	303.9	75.56
0.25	2	1079.6	352.3	727.3	1031.2	17.07
0.125	3	589.4	431.8	157.6	1188.8	4.39
0.0625	4	429.4	398.8	30.6	1219.4	1.93
pan	pan	493.2	469.2	24	1243.4	0
			Total	1243.4		

Percent error: 0.13 d10 : 0.205

Well: 983 Auger flight (ft.): 0-5 Depth range (ft.): 3' - 4' 4"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	422.8	403.2	19.6	19.6	98.4
2	-1	369.9	356.9	13	32.6	97.34
1	0	346.2	318.9	27.3	59.9	95.11
0.5	1	508.8	301.3	207.5	267.4	78.17
0.25	2	1134.9	352.2	782.7	1050.1	14.28
0.125	3	567.6	431.7	135.9	1186	3.18
0.0625	4	422.7	398.8	23.9	1209.9	1.23
pan	pan	484.5	469.4	15.1	1225	0
			Total	1225		

Percent error: 0.02 d10 : 0.15

Well: 984 Auger flight (ft.): 0-5 Depth range (ft.): 1' - 3' 4"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	624.3	427.7	196.6	196.6	91
2	-1	550.6	434.2	116.4	313	85.68
1	0	697.5	401.3	296.2	609.2	72.12
0.5	1	1036.6	313	723.6	1332.8	39.01
0.25	2	1037.2	317	720.2	2053	6.05
0.15	2.75	386.9	334.3	52.6	2105.6	3.65
0.075	3.75	296.7	237.9	58.8	2164.4	0.96
0.045	4.5	241	231.4	9.6	2174	0.52
pan	pan	327.3	316	11.3	2185.3	0
			Total	2185.3		

Percent error: 0.42 d10 : 0.28

Well: 984 Auger flight (ft.): 0-5 Depth range (ft.): 3' 5" - 5'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	484.4	426.3	58.1	58.1	96.01
2	-1	477.3	428.4	48.9	107	92.65
1	0	482.4	395.4	87	194	86.68
0.5	1	568.7	315.2	253.5	447.5	69.28
0.25	2	958.7	391.9	566.8	1014.3	30.37
0.125	3	725.6	334.4	391.2	1405.5	3.51
0.0625	4	271.5	249	22.5	1428	1.97
pan	pan	344.8	316.1	28.7	1456.7	0
			Total	1456.7		

Percent error: 3.21 d10 : 0.15

Well: 984 Auger flight (ft.): 5-10 Depth range (ft.): 6' - 8'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	406.8	402.6	4.2	4.2	99.76
2	-1	363.4	356.5	6.9	11.1	99.37
1	0	344.2	317.5	26.7	37.8	97.86
0.5	1	1244.6	301.1	943.5	981.3	44.52
0.25	2	964.5	352.9	611.6	1592.9	9.94
0.125	3	539.8	432	107.8	1700.7	3.84
0.0625	4	456.4	399.7	56.7	1757.4	0.64
pan	pan	480.6	469.3	11.3	1768.7	0
			Total	1768.7		

Percent error: 0 d10 : 0.22

Well: 984 Auger flight (ft.): 5-10 Depth range (ft.): 8' - 9' 5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
2	-1	429.7	428.7	1	1	99.89
1	0	396.3	395.4	0.9	1.9	99.79
0.5	1	328.5	313.4	15.1	17	98.16
0.25	2	917.8	391.8	526	543	41.32
0.177	2.5	519.1	255	264.1	807.1	12.78
0.0625	4	357.4	249.4	108	915.1	1.11
0.038	4.75	317.8	312.5	5.3	920.4	0.54
pan	pan	321.2	316.2	5	925.4	0
			Total	925.4		

Percent error: 4.69 d10 : 0.205

Well: 984 Auger flight (ft.): 10-15 Depth range (ft.): 10' 1" - 10' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	450.5	402.5	48	48	93.84
2	-1	370	356	14	62	92.04
1	0	345.1	317.7	27.4	89.4	88.52
0.5	1	493.5	301	192.5	281.9	63.8
0.25	2	608.7	276.6	332.1	614	21.16
0.15	2.75	414.3	333.9	80.4	694.4	10.84
0.075	3.75	361.6	319.9	41.7	736.1	5.48
0.045	4.5	312.7	303.4	9.3	745.4	4.29
pan	pan	502.5	469.1	33.4	778.8	0
			Total	778.8		

Percent error: -0.1 d10 : 0.12

Well: 984 Auger flight (ft.): 10-15 Depth range (ft.): 11' - 14' 3"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
1	0	396.9	394.8	2.1	2.1	96.97
0.5	1	317.8	313	4.8	6.9	90.03
0.25	2	493.5	427	66.5	73.4	58.79
0.15	2.75	1187.2	252.2	935	1008.4	63.83
0.09	3.5	1250.7	239	1011.7	2020.1	27.54
0.0625	4	699.3	253.4	445.9	2466	11.54
0.053	4.25	296.1	239.2	56.9	2522.9	9.5
0.045	4.5	248.9	231.4	17.5	2540.4	8.87
0.037	4.75	298.4	229.2	69.2	2609.6	6.39
pan	pan	394.2	216.1	178.1	2787.7	0
			Total	2787.7		

Percent error: -2.5 d10 : 0.052

Well: 984 Auger flight (ft.): 15-20 Depth range (ft.): 16' 0.75" - 17' 1.25"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	404.3	402.3	2	2	99.77
2	-1	360.2	354	6.2	8.2	99.06
1	0	312.9	312.8	0.1	8.3	99.05
0.5	1	381.2	299.6	81.6	89.9	89.7
0.25	2	835.9	316.7	519.2	609.1	30.2
0.125	3	626	430.7	195.3	804.4	7.82
0.0625	4	428.9	398.6	30.3	834.7	4.34
pan	pan	507.1	469.2	37.9	872.6	0
			Total	872.6		

Percent error: 0.24 d10 : 0.15

Well: 984 Auger flight (ft.): 20-25 Depth range (ft.): 20' - 21' 4.25"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
1	0	318.6	317.5	1.1	1.1	99.89
0.5	1	316.3	299.3	17	18.1	98.24
0.25	2	308.2	276.4	31.8	49.9	95.15
0.106	3.25	301.7	238.2	63.5	113.4	88.97
0.09	3.5	254.7	238.3	16.4	129.8	87.37
0.053	4.25	1016.9	239	777.9	907.7	11.69
0.045	4.5	310	303.4	6.6	914.3	11.05
0.038	4.75	272.8	229.1	43.7	958	6.8
pan	pan	539.2	469.3	69.9	1027.9	0
			Total	1027.9		

Percent error: 3.69 d10 : 0.046

Well: 984 Auger flight (ft.): 20-25 Depth range (ft.): 21' 4.5" - 22' 2.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	526.5	403	123.5	123.5	86.19
2	-1	509.7	354.6	155.1	278.6	68.84
1	0	493.7	315.9	177.8	456.4	48.95
0.5	1	503.9	308.2	195.7	652.1	27.06
0.25	2	489.1	318.4	170.7	822.8	7.96
0.125	3	466.7	431.6	35.1	857.9	4.04
0.0625	4	424	398.9	25.1	883	1.23
pan	pan	480.3	469.3	11	894	0
			Total	894		

Percent error: 1.53 d10 : 0.28

Well: 984 Auger flight (ft.): 20-25 Depth range (ft.): 22' 3" - 23' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	641.2	403	238.2	238.2	86.62
2	-1	570	356	214	452.2	74.61
1	0	591.9	316.1	275.8	728	59.12
0.5	1	725.4	300.5	424.9	1152.9	35.26
0.25	2	780.7	352.2	428.5	1581.4	11.2
0.125	3	567.1	431.4	135.7	1717.1	3.58
0.0625	4	440.3	399.2	41.1	1758.2	1.27
pan	pan	492.1	469.4	22.7	1780.9	0
			Total	1780.9		

Percent error: 0.36 d10 : 0.22

Well: 011 Auger flight (ft.): 0-5 Depth range (ft.): 8" - 1'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	403.3	402.8	0.5	0.5	99.77
2	-1	355.9	354.4	1.5	2	99.06
1	0	321.3	315.3	6	8	96.26
0.5	1	372.9	299.9	73	81	62.11
0.25	2	445	351	94	175	18.15
0.125	3	460.2	430.7	29.5	204.5	4.35
0.0625	4	399.8	398.5	1.3	205.8	3.74
pan	pan	477.2	469.2	8	213.8	0
			Total	213.8		

Percent error: -0.1 d10 : 0.2

Well: 011 Auger flight (ft.): 0-5 Depth range (ft.): 1' 7" - 1' 10.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	425.8	425.7	0.1	0.1	99.95
2	-1	429	428.3	0.7	0.8	99.59
1	0	398.6	395.3	3.3	4.1	97.92
0.5	1	345.3	312.2	33.1	37.2	81.14
0.25	2	483.1	390.7	92.4	129.6	34.28
0.125	3	381.1	334	47.1	176.7	10.4
0.0625	4	255.1	249	6.1	182.8	7.3
pan	pan	330.6	316.2	14.4	197.2	0
			Total	197.2		

Percent error: 0.51 d10 : 0.12

Well: 011 Auger flight (ft.): 0-5 Depth range (ft.): 2' 9" - 2' 10"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	405	402.7	2.3	2.3	99.03
2	-1	355.4	354.3	1.1	3.4	98.56
1	0	319.2	315.1	4.1	7.5	96.83
0.5	1	345.5	299.8	45.7	53.2	77.51
0.25	2	472.7	351.6	121.1	174.3	26.33
0.125	3	479.4	431.7	47.7	222	6.17
0.0625	4	410	399.8	10.2	232.2	1.86
pan	pan	473.7	469.3	4.4	236.6	0
			Total	236.6		

Percent error: 0.63 d10 : 0.16

Well: 012 Auger flight (ft.): 0-5 Depth range (ft.): 1' 1.5" - 1' 9"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	427	425.7	1.3	1.3	99.74
2	-1	430.3	428.1	2.2	3.5	99.3
1	0	408.7	394.1	14.6	18.1	96.4
0.5	1	463	313.9	149.1	167.2	66.74
0.25	2	622.3	390.9	231.4	398.6	20.71
0.125	3	422.5	334.1	88.4	487	3.12
0.0625	4	253.8	248.9	4.9	491.9	2.15
pan	pan	327.1	316.3	10.8	502.7	0
			Total	502.7		

Percent error: 0.08 d10 : 0.19

Well: 012 Auger flight (ft.): 0-5 Depth range (ft.): 3' 2" - 3' 4"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426	425.7	0.3	0.3	99.92
2	-1	431.7	428.3	3.4	3.7	98.96
1	0	411.1	395.4	15.7	19.4	94.57
0.5	1	417.8	316.1	101.7	121.1	66.11
0.25	2	576.6	393.1	183.5	304.6	14.75
0.125	3	383.5	334.4	49.1	353.7	1.01
0.0625	4	252.1	249	3.1	356.8	0.14
pan	pan	316.8	316.3	0.5	357.3	0
			Total	357.3		

Percent error: 2.12 d10 : 0.22

Well: 012 Auger flight (ft.): 0-5 Depth range (ft.): 3' 6"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426.3	425.8	0.5	0.5	99.83
2	-1	429.2	428	1.2	1.7	99.42
1	0	403.4	394.1	9.3	11	96.21
0.5	1	396.1	314.6	81.5	92.5	68.17
0.25	2	531.7	391.3	140.4	232.9	19.86
0.125	3	386.7	334.3	52.4	285.3	1.82
0.0625	4	252.5	248.8	3.7	289	0.55
pan	pan	317.8	316.2	1.6	290.6	0
			Total	290.6		

Percent error: 1.13 d10 : 0.2

Well: 013 Auger flight (ft.): 20-25 Depth range (ft.): 20' 3" - 21'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	428.9	425.7	3.2	3.2	99.45
2	-1	429	428.4	0.6	3.8	99.35
1	0	397.7	395.3	2.4	6.2	98.93
0.5	1	346.9	312.3	34.6	40.8	92.97
0.25	2	725	391.8	333.2	374	35.55
0.125	3	503	334.4	168.6	542.6	6.5
0.0625	4	275.1	249.4	25.7	568.3	2.07
pan	pan	328.4	316.4	12	580.3	0
			Total	580.3		

Percent error: 0.21 d10 : 0.15

Well: 013 Auger flight (ft.): 20-25 Depth range (ft.): 21' - 21' 6.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
2	-1	356	318	38	38	92.11
1	0	318	317.8	0.2	38.2	92.07
0.5	1	301.8	299.2	2.6	40.8	91.53
0.25	2	463.2	277.8	185.4	226.2	53.05
0.15	2.75	450.2	334.5	115.7	341.9	29.04
0.075	3.75	341.8	237.8	104	445.9	7.45
0.045	4.5	325.5	303.3	22.2	468.1	2.84
pan	pan	482.5	469.1	13.4	481.5	0.06
			Total	481.5		

Percent error: -0.4 d10 : 0.055

Well: 013 Auger flight (ft.): 20-25 Depth range (ft.): 21' 6.5" - 22' 2.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	0	0	0	0	100
2	-1	0	0	0	0	100
1	0	0	0	0	0	100
0.5	1	299.7	299.4	0.3	0.3	99.95
0.25	2	315.6	277.3	38.3	38.6	93.22
0.106	3.25	583.2	239.1	344.1	382.7	32.8
0.053	4.25	415.9	238.8	177.1	559.8	1.7
0.038	4.75	233	228.8	4.2	564	0.97
pan	pan	474.9	469.4	5.5	569.5	0
			Total	569.5		

Percent error: 0.28 d10 : 0.07

Well: 013 Auger flight (ft.): 30-35 Depth range (ft.): 31' 3" - 31' 9.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	430.1	425.7	4.4	4.4	98.08
2	-1	433	428.3	4.7	9.1	96.02
1	0	401.9	395.3	6.6	15.7	93.13
0.5	1	325.9	312.3	13.6	29.3	87.18
0.25	2	415.2	391	24.2	53.5	76.6
0.125	3	431	334.1	96.9	150.4	34.21
0.0625	4	307.1	249.1	58	208.4	8.84
pan	pan	336.4	316.2	20.2	228.6	0
			Total	228.6		

Percent error: -0.9 d10 : 0.065

Well: 013 Auger flight (ft.): 30-35 Depth range (ft.): 31' 7.5" - 31' 10.8"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426	425.6	0.4	0.4	99.92
2	-1	429.3	428.3	1	1.4	99.71
1	0	398.9	395.2	3.7	5.1	98.93
0.5	1	321.9	311.9	10	15.1	96.83
0.25	2	428.2	390.6	37.6	52.7	88.94
0.125	3	649.4	334.1	315.3	368	22.79
0.0625	4	302.2	249.1	53.1	421.1	11.64
pan	pan	371.7	316.2	55.5	476.6	0
			Total	476.6		

Percent error: 0.08 d10 : 0.06

Well: 013 Auger flight (ft.): 30-35 Depth range (ft.): 31' 10.8" - 32'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	445.2	425.9	19.3	19.3	77.4
2	-1	442	428.4	13.6	32.9	61.48
1	0	404.1	395.4	8.7	41.6	51.29
0.5	1	319.1	312	7.1	48.7	42.97
0.25	2	401.4	390.7	10.7	59.4	30.44
0.125	3	345.2	334	11.2	70.6	17.33
0.0625	4	258.9	249	9.9	80.5	5.74
pan	pan	321.1	316.2	4.9	85.4	0
			Total	85.4		

Percent error: -0.7 d10 : 0.075

Well: 013 Auger flight (ft.): 30-35 Depth range (ft.): 32' 8" - 33' 3.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	442.9	402.7	40.2	40.2	92.44
2	-1	425.9	354.7	71.2	111.4	79.04
1	0	407.6	315.7	91.9	203.3	61.75
0.5	1	420	300.7	119.3	322.6	39.3
0.25	2	480.6	351.7	128.9	451.5	15.05
0.125	3	493.2	430.8	62.4	513.9	3.31
0.0625	4	407.4	398.6	8.8	522.7	1.66
pan	pan	478	469.2	8.8	531.5	0
			Total	531.5		

Percent error: 0.34 d10 : 0.2

Well: 019 Auger flight (ft.): 0-5 Depth range (ft.): 1' 7" - 2' 3"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	477.3	403.1	74.2	74.2	88.79
2	-1	406.4	354.5	51.9	126.1	80.95
1	0	433.2	316	117.2	243.3	63.24
0.5	1	488.9	300.1	188.8	432.1	34.71
0.25	2	498.5	351.2	147.3	579.4	12.45
0.125	3	489.3	430.8	58.5	637.9	3.61
0.0625	4	408.7	398.6	10.1	648	2.09
pan	pan	483.1	469.3	13.8	661.8	0
			Total	661.8		

Percent error: 0.45 d10 : 0.025

Well: 019 Auger flight (ft.): 0-5 Depth range (ft.): 2' 3.25" - 3' 2"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	453	426.3	26.7	26.7	96.83
2	-1	481.7	428.5	53.2	79.9	90.5
1	0	480	395.4	84.6	164.5	80.44
0.5	1	463.2	313.5	149.7	314.2	62.65
0.25	2	651.2	427	224.2	538.4	36
0.106	3.25	567.2	321.1	246.1	784.5	6.74
0.0625	4	285.6	252.6	33	817.5	2.82
pan	pan	339.8	316.1	23.7	841.2	0
			Total	841.2		

Percent error: 0.28 d10 : 0.12

Well: 019 Auger flight (ft.): 0-5 Depth range (ft.): 3' 2.5" - 4' 2.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	446.3	402.6	43.7	43.7	94.88
2	-1	394.1	354.3	39.8	83.5	90.22
1	0	356.3	315.2	41.1	124.6	85.4
0.5	1	388.1	299.8	88.3	212.9	75.06
0.25	2	506.9	351.2	155.7	368.6	56.81
0.125	3	734.4	432.3	302.1	670.7	21.42
0.0625	4	473.6	399.6	74	744.7	12.75
pan	pan	578.1	469.3	108.8	853.5	0
			Total	853.5		

Percent error: 0.57 d10 : 0.06

Well: 019 Auger flight (ft.): 5-10 Depth range (ft.): 5' 0.5" - 5' 10.25"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	475.6	402.3	73.3	73.3	90.31
2	-1	422.2	354.2	68	141.3	81.33
1	0	409.6	312.9	96.7	238	68.55
0.5	1	548.4	299.3	249.1	487.1	35.63
0.25	2	533	315.6	217.4	704.5	6.9
0.125	3	467.7	430.8	36.9	741.4	2.02
0.0625	4	402.2	398.5	3.7	745.1	1.53
pan	pan	480.8	469.2	11.6	756.7	0
			Total	756.7		

Percent error: 0.3 d10 : 0.28

Well: 019 Auger flight (ft.): 5-10 Depth range (ft.): 5' 11" - 6' 1"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	428.3	402.5	25.8	25.8	84.96
2	-1	361.6	356.5	5.1	30.9	81.98
1	0	325.2	317.7	7.5	38.4	77.61
0.5	1	318.5	299.1	19.4	57.8	66.3
0.25	2	319.1	276.3	42.8	100.6	41.34
0.106	3.25	283.8	237.8	46	146.6	14.52
0.053	4.25	248.1	238.5	9.6	156.2	8.92
0.038	4.75	233.4	228.7	4.7	160.9	6.18
pan	pan	479.8	469.2	10.6	171.5	0
			Total	171.5		

Percent error: -0.1 d10 : 0.053

Well: 019 Auger flight (ft.): 5-10 Depth range (ft.): 6' 1.5" - 7' 4"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	629.6	426.4	203.2	203.2	82.97
2	-1	577.6	429.1	148.5	351.7	70.52
1	0	593.3	396.7	196.6	548.3	54.05
0.5	1	564.5	314.7	249.8	798.1	33.11
0.25	2	638.4	391.3	247.1	1045.2	12.4
0.125	3	458.5	334.1	124.4	1169.6	1.98
0.0625	4	260.5	249.1	11.4	1181	1.02
pan	pan	328.4	316.2	12.2	1193.2	0
			Total	1193.2		

Percent error: 0.3 d10 : 0.21

Well: 019 Auger flight (ft.): 5-10 Depth range (ft.): 7' 4.5" - 8' 4.25"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
2	-1	429	428.6	0.4	0.4	99.95
1	0	397	395.1	1.9	2.3	99.74
0.5	1	328.5	313.1	15.4	17.7	97.96
0.25	2	540.6	391	149.6	167.3	80.73
0.177	2.5	450.1	254.9	195.2	362.5	58.26
0.0625	4	661.4	249.2	412.2	774.7	10.79
0.037	4.75	354.6	312.9	41.7	816.4	5.99
pan	pan	368.2	316.2	52	868.4	0
			Total	868.4		

Percent error: 0 d10 : 0.006

Well: 019 Auger flight (ft.): 10-15 Depth range (ft.): 10' 2.5" - 11'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	411.6	402.6	9	9	98.43
2	-1	356.5	354.3	2.2	11.2	98.05
1	0	320.1	315	5.1	16.3	97.16
0.5	1	355.1	299.9	55.2	71.5	87.54
0.25	2	671.5	351.9	319.6	391.1	31.84
0.125	3	570.5	430.9	139.6	530.7	7.51
0.0625	4	421.9	398.7	23.2	553.9	3.47
pan	pan	489.2	469.3	19.9	573.8	0
			Total	573.8		

Percent error: -0.2 d10 : 0.13

Well: 019 Auger flight (ft.): 10-15 Depth range (ft.): 11' - 13' 5.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	410.7	402.4	8.3	8.3	99.59
2	-1	356.1	352.7	3.4	11.7	99.42
1	0	317.3	309.4	7.9	19.6	99.03
0.5	1	331.1	270.7	60.4	80	96.04
0.25	2	1402	277.6	1124.4	1204.4	40.44
0.15	2.75	663.2	54.8	608.4	1812.8	10.35
0.075	3.75	402.4	213	189.4	2002.2	0.98
0.045	4.5	304.7	300.1	4.6	2006.8	0.76
pan	pan	476.6	461.3	15.3	2022.1	0
			Total	2022.1		

Percent error: 0.54 d10 : 0.13

Well: 019 Auger flight (ft.): 15-20 Depth range (ft.): 15' 1" - 15' 8.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	410.3	402.8	7.5	7.5	98.66
2	-1	368.8	354.4	14.4	21.9	96.09
1	0	346.3	315.1	31.2	53.1	90.52
0.5	1	463.1	300	163.1	216.2	61.4
0.25	2	542.2	350.9	191.3	407.5	27.25
0.125	3	559.4	430.7	128.7	536.2	4.27
0.0625	4	410.6	398.6	12	548.2	2.12
pan	pan	481.2	469.3	11.9	560.1	0
			Total	560.1		

Percent error: -0.1 d10 : 0.13

Well: 019 Auger flight (ft.): 15-20 Depth range (ft.): 15' 9.5" - 18' 6.25"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	0	0	0	0	100
2	-1	0.4	0	0.4	0.4	99.98
1	0	396.2	394.5	1.7	2.1	99.91
0.5	1	322.4	303.6	18.8	20.9	99.11
0.25	2	1445.5	428.5	1017	1037.9	56
0.106	3.25	1593.5	322.2	1271.3	2309.2	2.1
0.0625	4	267.4	237.5	29.9	2339.1	0.84
pan	pan	325.5	305.8	19.7	2358.8	0
			Total	2358.8		

Percent error: 0.45 d10 : 0.12

Well: 019 Auger flight (ft.): 20-25 Depth range (ft.): 20' 0.5" - 21' 8"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	474.3	425.6	48.7	48.7	96.03
2	-1	441.6	428	13.6	62.3	94.92
1	0	423.6	394.8	28.8	91.1	92.57
0.5	1	567.6	313.6	254	345.1	71.84
0.25	2	903.4	391.5	511.9	857	30.07
0.125	3	650	334.1	315.9	1172.9	4.29
0.0625	4	285.3	249.1	36.2	1209.1	1.34
pan	pan	332.7	316.3	16.4	1225.5	0
			Total	1225.5		

Percent error: 0.24 d10 : 0.14

Well: 019 Auger flight (ft.): 20-25 Depth range (ft.): 21' 8.5" - 23' 6.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	444.9	426.1	18.8	18.8	98.79
2	-1	438.6	428.1	10.5	29.3	98.12
1	0	446.2	395.2	51	80.3	94.84
0.5	1	655.1	315.1	340	420.3	72.98
0.25	2	948.4	392.1	556.3	976.6	37.22
0.125	3	840.7	334.3	506.4	1483	4.67
0.0625	4	295.3	249	46.3	1529.3	1.69
pan	pan	342.6	316.3	26.3	1555.6	0
			Total	1555.6		

Percent error: -0.24 d10 : 0.13

Well: 019 Auger flight (ft.): 20-25 Depth range (ft.): 23' 7.25" - 24' 2"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	565.2	426	139.2	139.2	76.16
2	-1	448.2	428.5	19.7	158.9	72.79
1	0	434.3	395	39.3	198.2	66.06
0.5	1	357.7	313	44.7	242.9	58.4
0.25	2	402.4	315.8	86.6	329.5	43.57
0.15	2.75	462.3	334	128.3	457.8	21.6
0.075	3.75	309.2	237.6	71.6	529.4	9.33
0.045	4.5	255.5	231.2	24.3	553.7	5.17
pan	pan	346.2	316	30.2	583.9	0
			Total	583.9		

Percent error: 0.1 d10 : 0.08

Well: 019 Auger flight (ft.): 25-30 Depth range (ft.): 25' - 26' 2"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	513	425.8	87.2	87.2	92.05
2	-1	440.2	428.5	11.7	98.9	90.99
1	0	421.6	395.5	26.1	125	88.61
0.5	1	358.2	312.2	46	171	84.41
0.25	2	695.9	390.8	305.1	476.1	56.6
0.125	3	870.3	334.2	536.1	1012.2	7.74
0.0625	4	287.1	249.2	37.9	1050.1	4.28
pan	pan	363.2	316.2	47	1097.1	0
			Total	1097.1		

Percent error: 0.18 d10 : 0.12

Well: 019 Auger flight (ft.): 25-30 Depth range (ft.): 26' 2.5" - 28' 4"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	439.6	426.2	13.4	13.4	99.35
2	-1	447.7	428.9	18.8	32.2	98.43
1	0	429.5	396	33.5	65.7	96.8
0.5	1	512.8	313.8	199	264.7	87.13
0.25	2	1440.1	392.2	1048	1312.6	36.16
0.125	3	1020.6	334.2	686.4	1999	2.78
0.0625	4	282	249.1	32.9	2031.9	1.18
pan	pan	340.3	316.1	24.2	2056.1	0
			Total	2056.1		

Percent error: 0.02 d10 : 0.15

Well: 019 Auger flight (ft.): 25-30 Depth range (ft.): 28' 4.5" - 29' 6"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	535.5	427.6	107.9	107.9	90.77
2	-1	484.2	434	50.2	158.1	86.48
1	0	549.3	401	148.3	306.4	73.79
0.5	1	549.5	314.1	235.4	541.8	53.66
0.25	2	721.3	317.8	403.5	945.3	19.14
0.15	2.75	385.2	335.2	50	995.3	14.87
0.075	3.75	376.3	238.1	138.2	1133.5	3.05
0.045	4.5	242.3	231.6	10.7	1144.2	2.13
pan	pan	341.1	316.2	24.9	1169.1	0
			Total	1228.4		

Percent error: 0.25 d10 : 0.11

Well: 020 Auger flight (ft.): 0-5 Depth range (ft.): 1' 1" - 2' 3.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426.9	426	0.9	0.9	99.91
2	-1	430.9	428.1	2.8	3.7	99.64
1	0	417.9	395.2	22.7	26.4	97.43
0.5	1	514.6	314.8	199.8	226.2	77.99
0.25	2	843.3	391.7	451.6	677.8	34.03
0.125	3	611.6	334.4	277.2	955	7.06
0.0625	4	268.5	249	19.5	974.5	5.16
pan	pan	369.1	316.1	53	1027.5	0
			Total	1027.5		

Percent error: 1.59 d10 : 0.205

Well: 020 Auger flight (ft.): 0-5 Depth range (ft.): 2' 4.5" - 3' 4.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	452.2	425.8	26.4	26.4	97.16
2	-1	444.4	427.2	17.2	43.6	95.3
1	0	432	392.9	39.1	82.7	91.09
0.5	1	502.7	311.3	191.4	274.1	70.47
0.25	2	883.1	378.9	504.2	778.3	16.16
0.125	3	568.7	430.9	137.8	916.1	1.31
0.0625	4	407	398.6	8.4	924.5	0.41
pan	pan	320	316.2	3.8	928.3	0
			Total	928.3		

Percent error: 1.2 d10 : 0.21

Well: 020 Auger flight (ft.): 5-10 Depth range (ft.): 5' 6.5" - 6' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	452.8	403.2	49.6	49.6	96.06
2	-1	420	356.2	63.8	113.4	90.98
1	0	456.6	320.1	136.5	249.9	80.12
0.5	1	721.5	300.5	421	670.9	46.64
0.25	2	788.6	352.1	436.5	1107.4	11.92
0.125	3	550.8	431.3	119.5	1226.9	2.42
0.0625	4	418.1	399	19.1	1246	0.9
pan	pan	481	469.7	11.3	1257.3	0
			Total	1257.3		

Percent error: 0.41 d10 : 0.22

Well: 020 Auger flight (ft.): 5-10 Depth range (ft.): 7' 0.25" - 8' 1.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	477.1	425.8	51.3	51.3	94.57
2	-1	469.4	428.3	41.1	92.4	90.22
1	0	457.6	394.4	63.2	155.6	83.53
0.5	1	585.9	316.3	269.6	425.2	54.99
0.25	2	740.1	390.8	349.3	774.5	18.02
0.125	3	493.5	334.5	159	933.5	1.19
0.0625	4	257.7	248.8	8.9	942.4	0.24
pan	pan	318.5	316.2	2.3	944.7	0
			Total	944.7		

Percent error: 0.73 d10 : 0.2

Well: 020 Auger flight (ft.): 5-10 Depth range (ft.): 8' 2.25" - 8' 11"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	489.7	402.4	87.3	87.3	87.31
2	-1	374.5	354	20.5	107.8	84.33
1	0	348.8	312.6	36.2	144	79.07
0.5	1	383.8	298.7	85.1	229.1	66.71
0.25	2	602.7	315.5	287.2	516.3	24.97
0.125	3	563.3	430.7	132.6	648.9	5.7
0.0625	4	416.3	398.5	17.8	666.7	3.11
pan	pan	490.7	469.3	21.4	688.1	0
			Total	688.1		

Percent error: 0.39 d10 : 0.16

Well: 020 Auger flight (ft.): 10-15 Depth range (ft.): 10' 2.25" - 10' 7.75"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	0	0	0	0	100
2	-1	0	0	0	0	100
1	0	317.8	317.7	0.1	0.1	99.97
0.5	1	300	299.6	0.4	0.5	99.86
0.25	2	295	277.5	17.5	18	95.09
0.106	3.25	480.4	239.4	241	259	29.33
0.053	4.25	343.5	238.9	104.6	363.6	0.79
0.038	4.75	229.8	228.9	0.9	364.5	0.55
pan	pan	471.3	469.3	2	366.5	0
			Total	366.5		

Percent error: 0.22 d10 : 0.07

Well: 020 Auger flight (ft.): 10-15 Depth range (ft.): 10' 8" - 13' 10"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	409.2	402.5	6.7	6.7	99.6
2	-1	361.6	356.7	4.9	11.6	99.31
1	0	335.5	317.5	18	29.6	98.24
0.5	1	361.3	119.3	242	271.6	83.87
0.25	2	1263.2	277.2	986	1257.6	25.33
0.15	2.75	525.6	294.6	231	1488.6	11.61
0.075	3.75	349	221.9	127.1	1615.7	4.06
0.045	4.5	324.3	290.3	34	1649.7	2.04
pan	pan	488.6	454.2	34.4	1684.1	0
			Total	1684.1		

Percent error: 0.05 d10 : 0.12

Well: 020 Auger flight (ft.): 15-20 Depth range (ft.): 15' 1.5" - 15' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	430.1	425.7	4.4	4.4	99.44
2	-1	438	428.2	9.8	14.2	98.18
1	0	427.7	395.1	32.6	46.8	94
0.5	1	412.1	312.4	99.7	146.5	81.21
0.25	2	743.3	390	353.3	499.8	35.89
0.125	3	561.3	333.8	227.5	727.3	6.71
0.0625	4	270.1	249	21.1	748.4	4
pan	pan	347	315.8	31.2	779.6	0
			Total	779.6		

Percent error: 0.21 d10 : 0.12

Well: 020 Auger flight (ft.): 15-20 Depth range (ft.): 16' 2" - 17'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
2	-1	429.1	428.8	0.3	0.3	99.97
1	0	396	395.8	0.2	0.5	99.95
0.5	1	315.1	313.5	1.6	2.1	99.78
0.125	3	1222.1	334.4	887.7	889.8	7.08
0.0625	4	266.9	249.4	17.5	907.3	5.25
0.053	4.25	325.9	319.9	6	913.3	4.63
0.045	4.5	415.4	405.3	10.1	923.4	3.57
pan	pan	350.4	316.2	34.2	957.6	0
			Total	957.6		

Percent error: 0.5 d10 : 0.12

Well: 020 Auger flight (ft.): 15-20 Depth range (ft.): 17' - 18' 2.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	403.1	402.3	0.8	0.8	99.92
2	-1	355.3	354.2	1.1	1.9	99.82
1	0	315.9	313.3	2.6	4.5	99.57
0.5	1	347.6	300.3	47.3	51.8	95.01
0.25	2	999.7	316.3	683.4	735.2	29.19
0.125	3	677.6	430.8	246.8	982	5.41
0.0625	4	425.8	398.5	27.3	1009.3	2.78
pan	pan	498.1	469.2	28.9	1038.2	0
			Total	1038.2		

Percent error: 0.05 d10 : 0.18

Well: 020 Auger flight (ft.): 20-25 Depth range (ft.): 20' - 21' 7.5"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	481.5	402.3	79.2	79.2	94.52
2	-1	413.5	354.2	59.3	138.5	90.42
1	0	440.9	313.3	127.6	266.1	81.6
0.5	1	677.7	300.6	377.1	643.2	55.52
0.25	2	897.7	316.2	581.5	1224.7	15.31
0.125	3	585.3	430.9	154.4	1379.1	4.63
0.0625	4	416.4	398.6	17.8	1396.9	3.4
pan	pan	518.4	469.2	49.2	1446.1	0
			Total	1446.1		

Percent error: 0.29 d10 : 0.2

Well: 020 Auger flight (ft.): 20-25 Depth range (ft.): 21' 7.5" - 22' 10"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426.5	426.2	0.3	0.3	99.97
2	-1	428.9	428.5	0.4	0.7	99.93
1	0	397.4	395.4	2	2.7	99.73
0.5	1	359.3	316.2	43.1	45.8	95.49
0.25	2	1226.1	430.6	795.5	841.3	17.24
0.106	3.25	488.2	322	166.2	1007.5	0.89
0.0625	4	260.2	252.7	7.5	1015	0.15
pan	pan	317.7	316.2	1.5	1016.5	0
			Total	1016.5		

Percent error: 0.65 d10 : 0.205

Well: 020 Auger flight (ft.): 20-25 Depth range (ft.): 22' 10.5" - 23' 9"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	405.4	402.2	3.2	3.2	99.58
2	-1	355.5	353.8	1.7	4.9	99.35
1	0	318.4	311.9	6.5	11.4	98.5
0.5	1	348.8	296.8	52	63.4	91.65
0.25	2	721.9	267.8	454.1	517.5	31.85
0.125	3	474	251.4	222.6	740.1	2.53
0.0625	4	264.8	249	15.8	755.9	0.45
pan	pan	472.7	469.3	3.4	759.3	0
			Total	759.3		

Percent error: 1.2 d10 : 0.18

Well: 020 Auger flight (ft.): 25-30 Depth range (ft.): 25' - 26' 2"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	404.2	403.1	1.1	1.1	99.89
2	-1	359.4	357	2.4	3.5	99.66
1	0	324.7	319.7	5	8.5	99.17
0.5	1	334	301.8	32.2	40.7	96.04
0.25	2	900.1	352.2	547.9	588.6	42.75
0.125	3	787.7	431.8	355.9	944.5	8.13
0.0625	4	456.7	399	57.7	1002.2	2.52
pan	pan	495.3	469.4	25.9	1028.1	0
			Total	1028.1		

Percent error: 0.17 d10 : 0.12

Well: 020 Auger flight (ft.): 25-30 Depth range (ft.): 26' 2" - 27' 8"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	411.5	402.5	9	9	99.31
2	-1	363.5	356.5	7	16	98.78
1	0	330.6	317.7	12.9	28.9	97.79
0.5	1	327	299.4	27.6	56.5	95.69
0.25	2	306.3	276.5	29.8	86.3	93.41
0.106	3.25	1155.9	239.3	916.6	1002.9	23.41
0.053	4.25	508	239	269	1271.9	2.86
0.038	4.75	249.7	229	20.7	1292.6	1.28
pan	pan	486.1	469.3	16.8	1309.4	0
			Total	1309.4		

Percent error: 1.18 d10 : 0.08

Well: 020 Auger flight (ft.): 25-30 Depth range (ft.): 27' 8" - 29' 2"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	467.4	426.8	40.6	40.6	97.15
2	-1	460.5	430.6	29.9	70.5	95.04
1	0	446.4	398.1	48.3	118.8	91.65
0.5	1	400.1	313.1	87	205.8	85.53
0.25	2	1247.4	316.4	931	1136.8	20.08
0.15	2.75	449.2	334.3	114.9	1251.7	12.01
0.075	3.75	359.6	238	121.6	1373.3	3.46
0.045	4.5	256.3	231.5	24.8	1398.1	1.72
pan	pan	340.5	316.1	24.4	1422.5	0
			Total	1422.5		

Percent error: 0.13 d10 : 0.11

Well: 021 Auger flight (ft.): 0-5 Depth range (ft.): 1' - 2'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	426.6	426.5	0.1	0.1	99.99
2	-1	430.5	429.1	1.4	1.5	99.81
1	0	423.6	395.7	27.9	29.4	96.26
0.5	1	481.6	313.1	168.5	197.9	74.83
0.25	2	741	391.3	349.7	547.6	30.34
0.125	3	529.8	334.1	195.7	743.3	5.44
0.0625	4	262.1	249	13.1	756.4	3.78
pan	pan	345.7	316	29.7	786.1	0
			Total	786.1		

Percent error: -0.1 d10 : 0.14

Well: 021 Auger flight (ft.): 0-5 Depth range (ft.): 2' - 4' 7"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	479	402.6	76.4	76.4	96.7
2	-1	375.6	356.5	19.1	95.5	95.87
1	0	370.3	316.5	53.8	149.3	93.55
0.5	1	956.3	301	655.3	804.6	65.24
0.25	2	1537.1	352.5	1185	1989.2	14.06
0.125	3	619.6	351.2	268.4	2257.6	2.47
0.0625	4	431.8	390	41.8	2299.4	0.66
pan	pan	479.7	464.4	15.3	2314.7	0
			Total	2314.7		

Percent error: 1.27 d10 : 0.22

Well: 021 Auger flight (ft.): 5-10 Depth range (ft.): 6' 2" - 6' 11.75"

ieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	437.1	425.8	11.3	11.3	98.28
2	-1	440.9	428.3	12.6	23.9	96.36
1	0	440.6	396.4	44.2	68.1	89.63
0.5	1	571.6	318.7	252.9	321	51.1
0.25	2	662.6	393.1	269.5	590.5	10.04
0.125	3	398.1	334.3	63.8	654.3	0.32
0.0625	4	250.5	248.8	1.7	656	0.06
pan	pan	316.6	316.2	0.4	656.4	0
			Total	656.4		

Percent error: 1.65 d10 : 0.25

Well: 021 Auger flight (ft.): 5-10 Depth range (ft.): 7' 0.5" - 7' 11.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	563.3	402.3	161	161	81.24
2	-1	508.6	354.3	154.3	315.3	63.27
1	0	480.9	313	167.9	483.2	43.71
0.5	1	470.7	297.9	172.8	656	23.58
0.25	2	470.5	316.4	154.1	810.1	5.63
0.125	3	463.1	430.6	32.5	842.6	1.84
0.0625	4	403.6	398.5	5.1	847.7	1.25
pan	pan	480	469.3	10.7	858.4	0
			Total	858.4		

Percent error: 0.53 d10 : 0.3

Well: 021 Auger flight (ft.): 5-10 Depth range (ft.): 8' -8' 9.5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	595.7	425.8	169.9	169.9	80.63
2	-1	511.6	428.5	83.1	253	71.16
1	0	529.9	395.8	134.1	387.1	55.88
0.5	1	496.7	312.4	184.3	571.4	34.87
0.25	2	518.2	391	127.2	698.6	20.37
0.125	3	379.9	334.4	45.5	744.1	15.18
0.0625	4	357.8	249	108.8	852.9	2.78
pan	pan	340.7	316.3	24.4	877.3	0
			Total	877.3		

Percent error: 0.1 d10 : 0.09

Well: 021 Auger flight (ft.): 10-15 Depth range (ft.): 10' 1" - 11' 6"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	723.3	426.4	296.9	296.9	79.47
2	-1	628.3	429.7	198.6	495.5	65.73
1	0	726	397.4	328.6	824.1	43.01
0.5	1	682.9	313.6	369.3	1193.4	17.47
0.25	2	525.9	391.2	134.7	1328.1	8.15
0.125	3	439	334.3	104.7	1432.8	0.91
0.0625	4	254.2	249	5.2	1438	0.55
pan	pan	324.1	316.1	8	1446	0
			Total	1446		

Percent error: 0.28 d10 : 0.3

Well: 021 Auger flight (ft.): 10-15 Depth range (ft.): 11' 6.25" - 13' 5"

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	459.7	402.6	57.1	57.1	96.76
2	-1	430	356.8	73.2	130.3	92.62
1	0	455.3	320	135.3	265.6	84.95
0.5	1	1204.9	306	898.9	1164.5	34.01
0.25	2	723.4	278.2	445.2	1609.7	8.78
0.15	2.75	429.4	334.2	95.2	1704.9	3.38
0.053	3.75	361.7	320.6	41.1	1746	1.05
0.045	4.5	304.8	303.1	1.7	1747.7	0.96
pan	pan	478.1	461.2	16.9	1764.6	0
			Total	1764.6		

Percent error: 0 d10 : 0.28

Well: 021 Auger flight (ft.): 10-15 Depth range (ft.): 13' 5" - 14'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	441.6	402.2	39.4	39.4	92.63
2	-1	414.9	354	60.9	100.3	81.23
1	0	382.9	313.3	69.6	169.9	68.21
0.5	1	388.2	299.5	88.7	258.6	51.62
0.25	2	485.7	316	169.7	428.3	19.87
0.125	3	507.6	430.8	76.8	505.1	5.5
0.0625	4	405.2	398.6	6.6	511.7	4.27
pan	pan	492.1	469.3	22.8	534.5	0
			Total	534.5		

Percent error: 0.13 d10 : 0.18

Well: 021 Auger flight (ft.): 15-20 Depth range (ft.): 16' -17'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	429.2	425.8	3.4	3.4	99.6
2	-1	431.9	428.1	3.8	7.2	99.15
1	0	398.8	395.3	3.5	10.7	98.74
0.5	1	368.6	314.3	54.3	65	92.34
0.25	2	953.8	391.7	562.1	627.1	26.12
0.125	3	538.1	334.1	204	831.1	2.09
0.0625	4	258.3	248.9	9.4	840.5	0.98
pan	pan	324.6	316.3	8.3	848.8	0
			Total	848.8		

Percent error: 0.25 d10 : 0.19

Well: 021 Auger flight (ft.): 20-25 Depth range (ft.): 20' - 21'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	519.2	402.6	116.6	116.6	86.05
2	-1	472.8	354.9	117.9	234.5	71.95
1	0	507.1	314.7	192.4	426.9	48.94
0.5	1	521	300.2	220.8	647.7	22.52
0.25	2	439.6	316	123.6	771.3	7.74
0.125	3	467.8	430.9	36.9	808.2	3.33
0.0625	4	408	398.8	9.2	817.4	2.22
pan	pan	487.9	469.3	18.6	836	0
			Total	836		

Percent error: 0.31 d10 : 0.28

Well: 021 Auger flight (ft.): 20-25 Depth range (ft.): 21' - 22'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	581	425.8	155.2	155.2	84.29
2	-1	530.6	428.3	102.3	257.5	73.93
1	0	594.9	395.5	199.4	456.9	53.74
0.5	1	673.1	313.9	359.2	816.1	17.37
0.25	2	526.6	390.5	136.1	952.2	3.59
0.125	3	358.7	334	24.7	976.9	1.09
0.0625	4	253	248.8	4.2	981.1	0.67
pan	pan	322.7	316.1	6.6	987.7	0
			Total	987.7		

Percent error: 0.11 d10 : 0.37

Well: 021 Auger flight (ft.): 20-25 Depth range (ft.): 22' - 23'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	450.2	425.7	24.5	24.5	97.44
2	-1	464	428.2	35.8	60.3	93.69
1	0	477.7	395.5	82.2	142.5	85.08
0.5	1	801.2	314.3	486.9	629.4	34.11
0.25	2	648.1	391	257.1	886.5	7.2
0.125	3	393.5	334	59.5	946	0.97
0.0625	4	253.3	248.8	4.5	950.5	0.5
pan	pan	321	316.2	4.8	955.3	0
			Total	955.3		

Percent error: 0.17 d10 : 0.28

Well: 021 Auger flight (ft.): 20-25 Depth range (ft.): 23' - 24'

Sieve Opening (mm)	(phi)	Sieve+ sample (gm)	Sieve (gm)	Weight retained (gm)	Cumulative Weight Retained (gms)	Percent Finer (%)
4	-2	501.8	402.6	99.2	99.2	90.17
2	-1	426.8	354.6	72.2	171.4	83.01
1	0	388.4	314.6	73.8	245.2	75.69
0.5	1	581.4	301.3	280.1	525.3	47.93
0.25	2	719.7	316.4	403.3	928.6	7.95
0.125	3	497.5	430.6	66.9	995.5	1.32
0.0625	4	403.3	398.6	4.7	1000.2	0.85
pan	pan	477.9	469.3	8.6	1008.8	0
			Total	1008.8		

Percent error: 0.16 d10 : 0.27

Appendix A5 Hydraulic Conductivity Tables

Explanation

Well Number : 222
Depth : 0-5 feet
Recovery :12 inches

Depth		Effective Grain Diameter (mm) B	Hazen's K Lithologic Vertical Hydraulic Conductivity (cm/sec) C	Hazen's K Calculated Whole Core Hydraulic Conductivity (cm/sec) D	Permeameter Measurements: Lithologic Vertical Hydraulic Conductivity (cm/sec) E	Permeameter Measurements: Calculated Whole Core Vertical Hydraulic Conductivity (cm/sec) F	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec) G
0'	A	0.23	5.29×10^{-2}	5.00×10^{-2}	2.55×10^{-2}	3.44×10^{-2}	2.17×10^{-3}
		0.22	4.84×10^{-2}		6.65×10^{-2}		
1'				5.01×10^{-2} H		3.5×10^{-2} H	

0"

6"

A -- Stratigraphic analysis from visual core descriptions, Appendix A2.
B -- Data obtained from sieving analysis of core samples, Appendix A4.
C -- Hydraulic conductivity, K, calculated using the following equation, Hazen (1911):

$$K = C\,(d_{10})^2$$

where C is 100/(cm/sec) and d_{10} is the effective grain diameter.

D, F -- Bulk vertical hydraulic conductivity, K_z, calculated using the following equation, Leonards (1962):

$$K_z = \frac{z_1 + z_2}{\dfrac{z_1}{K_1} + \dfrac{z_2}{K_2}}$$

where z is the length of depth 1 and 2 (increasing depth) and K is the hydraulic conductivity of depths 1 and 2. Values in column D and F were calculated using data from column C and E, respectively.

E, G -- Measured hydraulic conductivity using a permeameter, Figure II.6
H -- Bulk horizontal hydraulic conducitivity, K_x calculated using the following equation, Leonards (1962):

$$K_x = \frac{K_1 z_1 + K_2 z_2}{z_1 + z_2}$$

Well Number : 702c
Depth : 0-5 feet
Recovery : 41.75 inches

Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
0' – 1'	Organics, no collection					
1' – 3'	0.23	5.29×10^{-2}	5.00×10^{-2}	n/a	n/a	2.17×10^{-3}
3' – 4'	0.22	4.84×10^{-2}				
			5.01×10^{-2}			

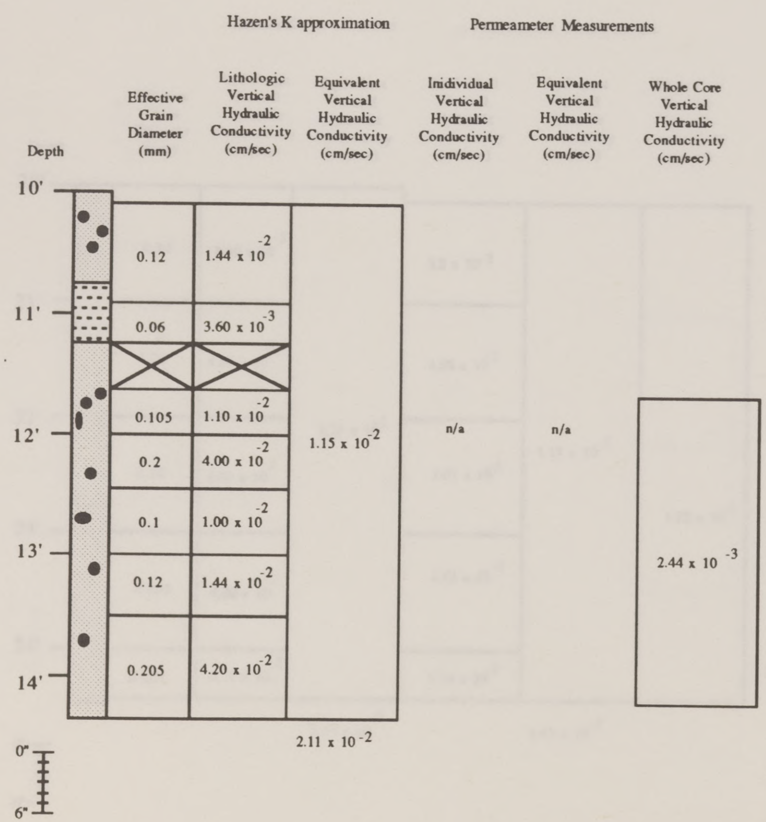
Scale: 0" – 6"

Well Number : 702c
Depth : 5-10 feet
Recovery : 13 inches

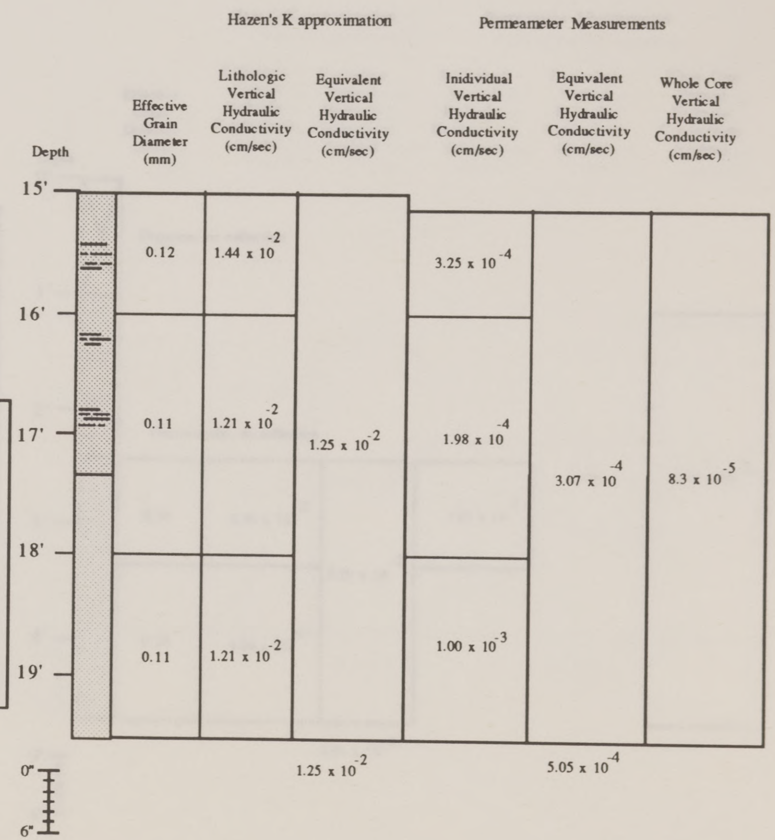
Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
5' – 6'	0.18	3.24×10^{-2}	n/a	n/a	n/a	2.37×10^{-3}

Scale: 0" – 6"

Well Number : 702c
Depth : 10-15 feet
Recovery : 30.5 inches



Well Number : 702c
Depth : 15-20 feet
Recovery : 52.5 inches



Well Number : 702c
Depth : 20-25 feet
Recovery : 51.5 inches

Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
20'	0.13	1.69×10^{-2}	3.27×10^{-2}	5.2×10^{-3}	1.15×10^{-2}	1.22×10^{-2}
21'	0.22	4.84×10^{-2}		1.96×10^{-2}		
22'	0.20	4.00×10^{-2}		1.67×10^{-2}		
23'	0.205	4.20×10^{-2}		1.43×10^{-2}		
24'	0.205	4.20×10^{-2}		1.74×10^{-2}		
			3.79×10^{-2}		1.45×10^{-2}	

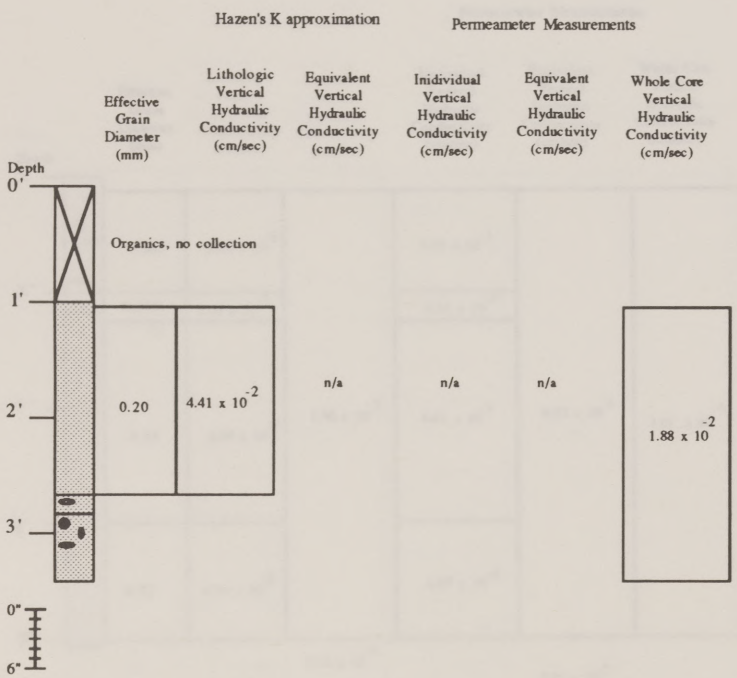
0" – 6"

Well Number : 980
Depth : 0-5 feet
Recovery : 42.5 inches

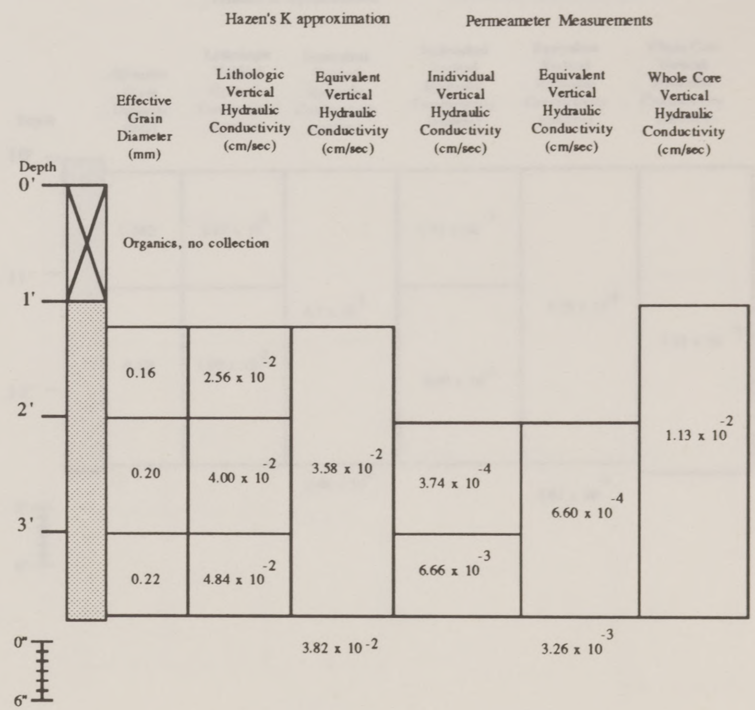
Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
0'	Organics, no collection					
1'–2'	Tree material, no collection					
3'	0.16	2.56×10^{-2}	3.29×10^{-2}	3.82×10^{-3}	n/a	1.40×10^{-2}
4'	0.20	4.00×10^{-2}				
			1.66×10^{-2}			

0" – 6"

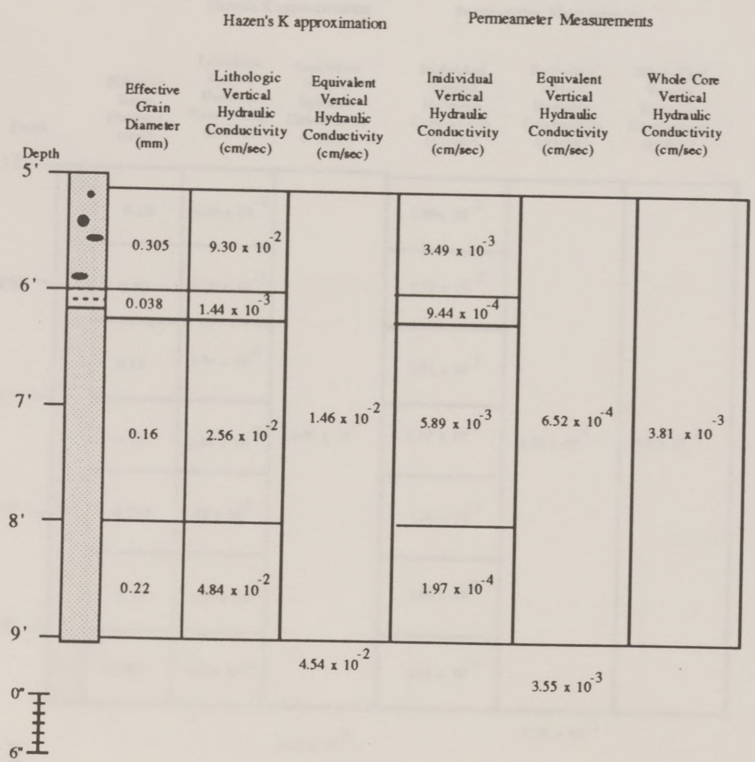
Well Number : 981
Depth : 0-5 feet
Recovery : 28 inches



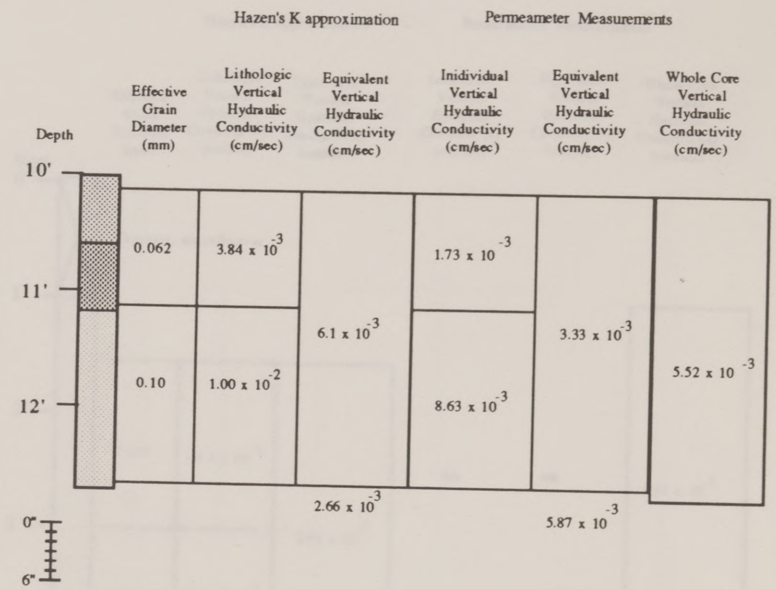
Well Number : 982
Depth : 0-5 feet
Recovery : 31.5 inches



Well Number : 982
Depth : 5-10 feet
Recovery : 47.5 inches



Well Number : 982
Depth : 10-15 feet
Recovery : 30 inches



Well Number : 982
Depth : 15-20 feet
Recovery : 55.5 inches

Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
15'	0.20	4.00×10^{-2}	3.06×10^{-2}	1.89×10^{-2}	1.28×10^{-2}	1.5×10^{-2}
16'	0.20	4.00×10^{-2}		1.72×10^{-2}		
	0.18	3.24×10^{-2}		1.59×10^{-2}		
17'	0.12	1.44×10^{-2}		9.12×10^{-3}		
18'	0.205	4.2×10^{-2}		1.30×10^{-2}		
	0.18	3.24×10^{-2}		1.03×10^{-2}		
19'	0.205	4.2×10^{-2}		1.13×10^{-2}		

3.47×10^{-2}

1.36×10^{-2}

0" – 6"

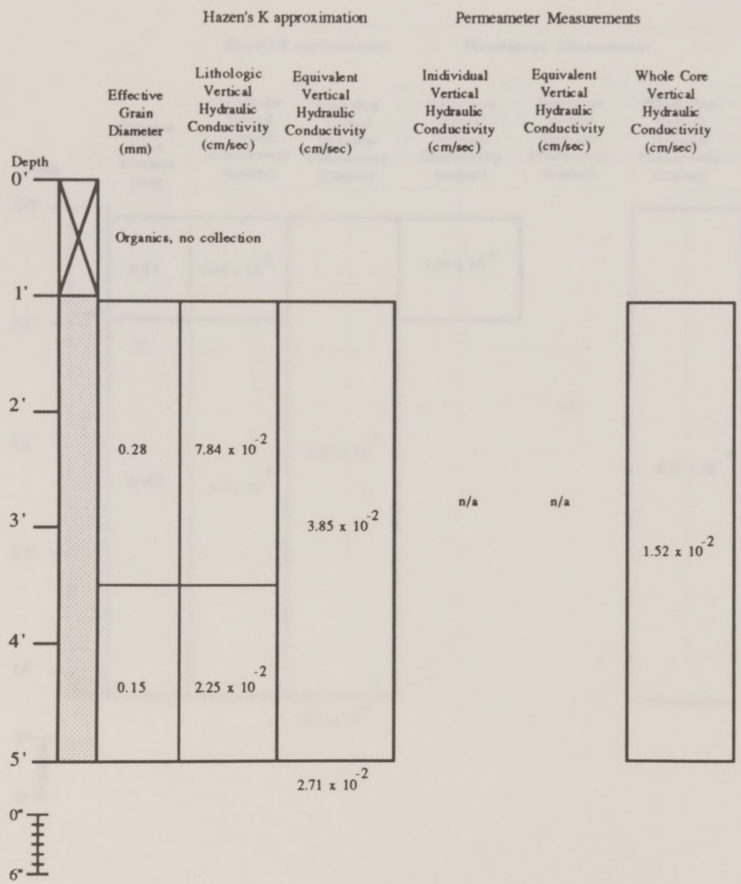
Well Number : 983
Depth : 0-5 feet
Recovery : 35 inches

Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
0'	Organics, no collection					
1'						
2'	0.205	4.2×10^{-2}	2.96×10^{-2}	n/a	n/a	9.43×10^{-3}
3'	0.15	2.25×10^{-2}				
4'						

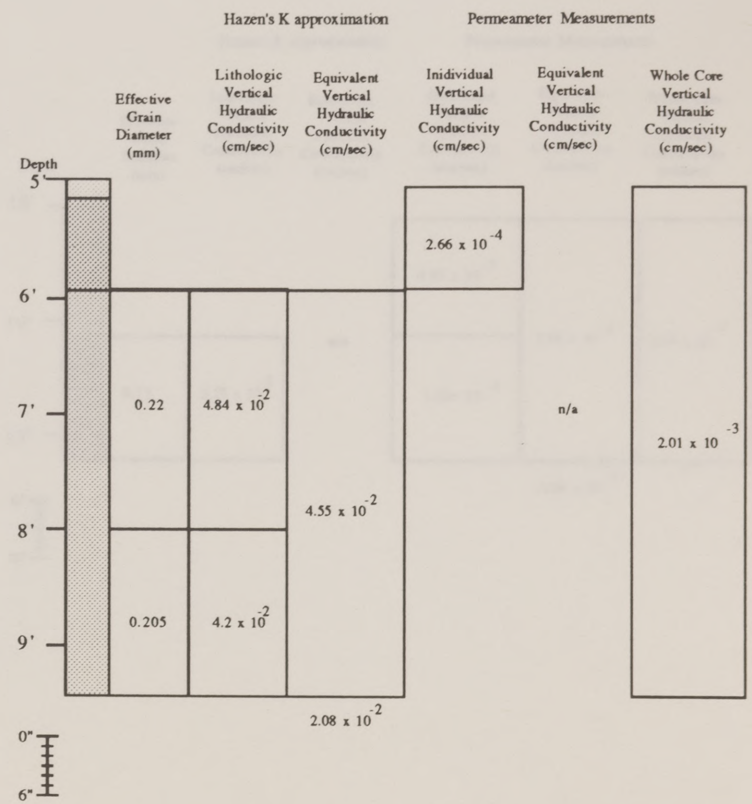
1.33×10^{-2}

0" – 6"

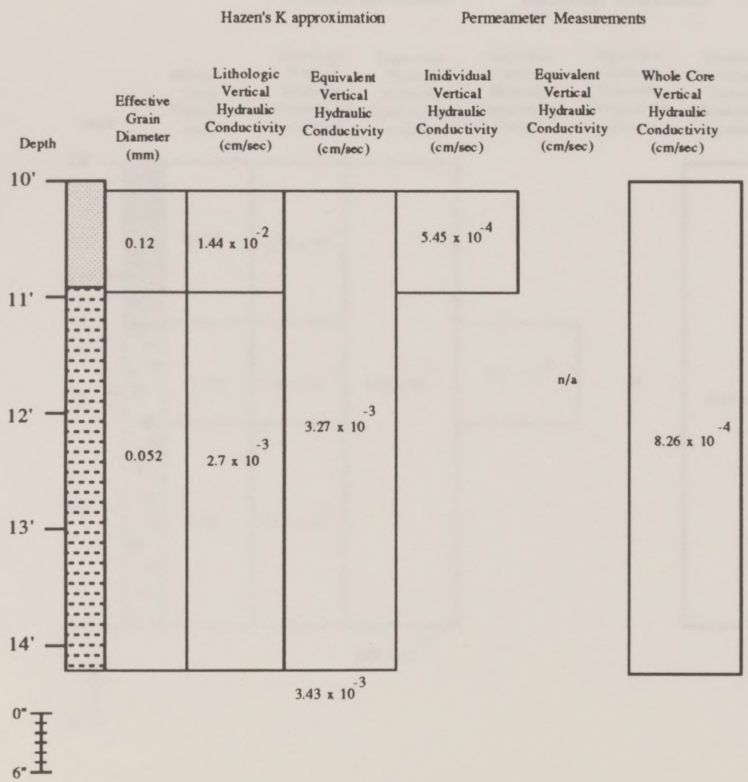
Well Number : 984
Depth : 0-5 feet
Recovery : 47.5 inches



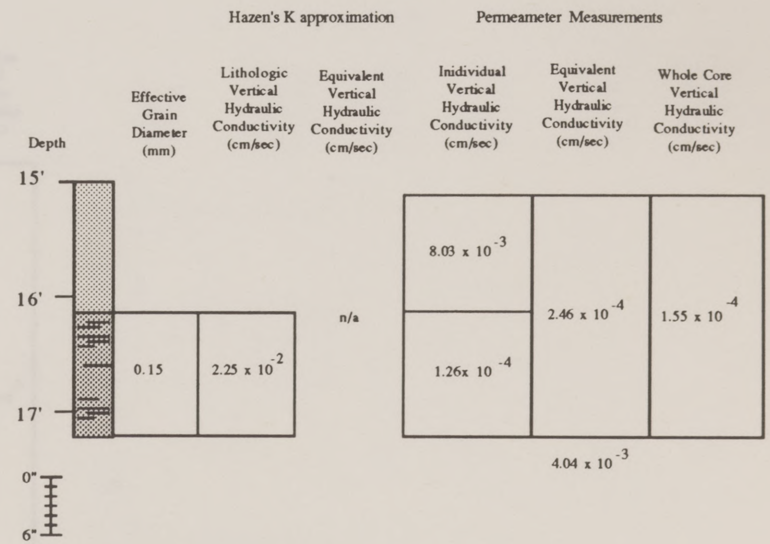
Well Number : 984
Depth : 5-10 feet
Recovery : 49.5 inches



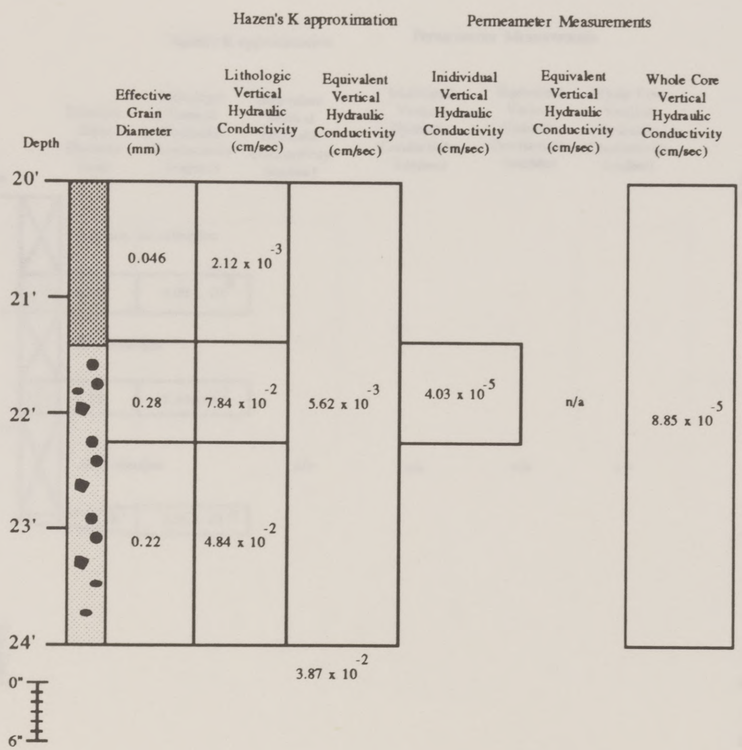
Well Number : 984
Depth : 10-15 feet
Recovery : 49 inches



Well Number : 984
Depth : 15-20 feet
Recovery : 25.25 inches



Well Number : 984
Depth : 20-25 feet
Recovery : 48 inches



Well Number : 011
Depth : 0-5 feet
Recovery : 8.5 inches

Depth		Hazen's K approximation		Permeameter Measurements		
	Effective Grain Diameter (mm)	Lithologic Vertical Hydraulic Conductivity (cm/sec)	Equivalent Vertical Hydraulic Conductivity (cm/sec)	Inidividual Vertical Hydraulic Conductivity (cm/sec)	Equivalent Vertical Hydraulic Conductivity (cm/sec)	Whole Core Vertical Hydraulic Conductivity (cm/sec)
0'	Organics, no collection					
	0.20	4.00×10^{-2}				
1'	No collection					
	0.12	1.44×10^{-2}				
2'	No collection		n/a	n/a	n/a	n/a
	0.16	2.56×10^{-2}				

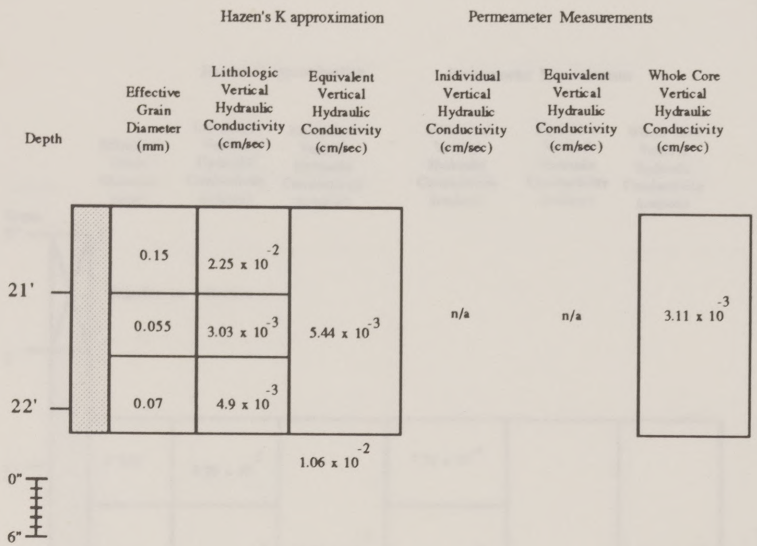
0" – 6"

Well Number : 012
Depth : 0-5 feet
Recovery : 10 inches

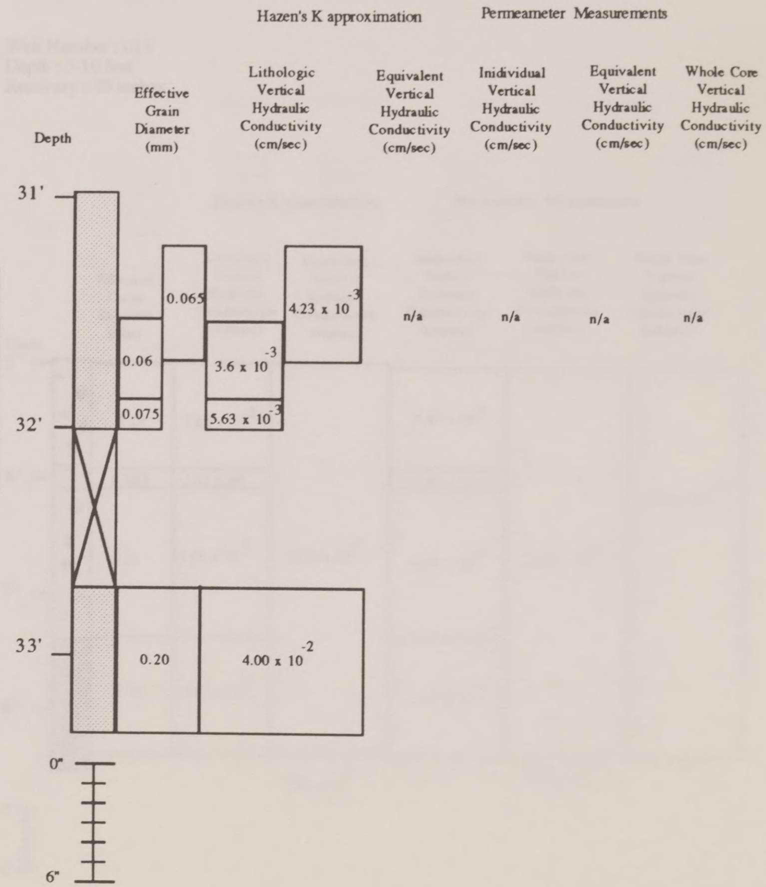
Depth		Hazen's K approximation		Permeameter Measurements		
	Effective Grain Diameter (mm)	Lithologic Vertical Hydraulic Conductivity (cm/sec)	Equivalent Vertical Hydraulic Conductivity (cm/sec)	Inidividual Vertical Hydraulic Conductivity (cm/sec)	Equivalent Vertical Hydraulic Conductivity (cm/sec)	Whole Core Vertical Hydraulic Conductivity (cm/sec)
0'	Organics, no collection					
1'	0.19	3.61×10^{-2}				
2'	No collection		n/a	n/a	n/a	n/a
3'	0.22	4.84×10^{-2}				
	No collection					
	0.16	4.00×10^{-2}				

0" – 6"

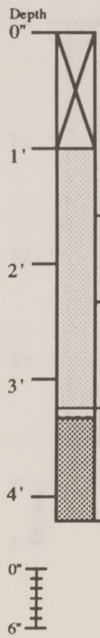
Well Number : 013
Depth : 20-25 feet
Recovery : 23.5 inches



Well Number : 013
Depth : 30-35 feet
Recovery : inches

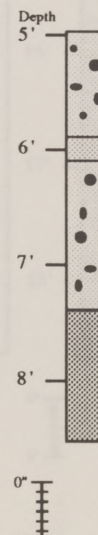


Well Number : 019
Depth : 0-5 feet
Recovery : 31.5 inches



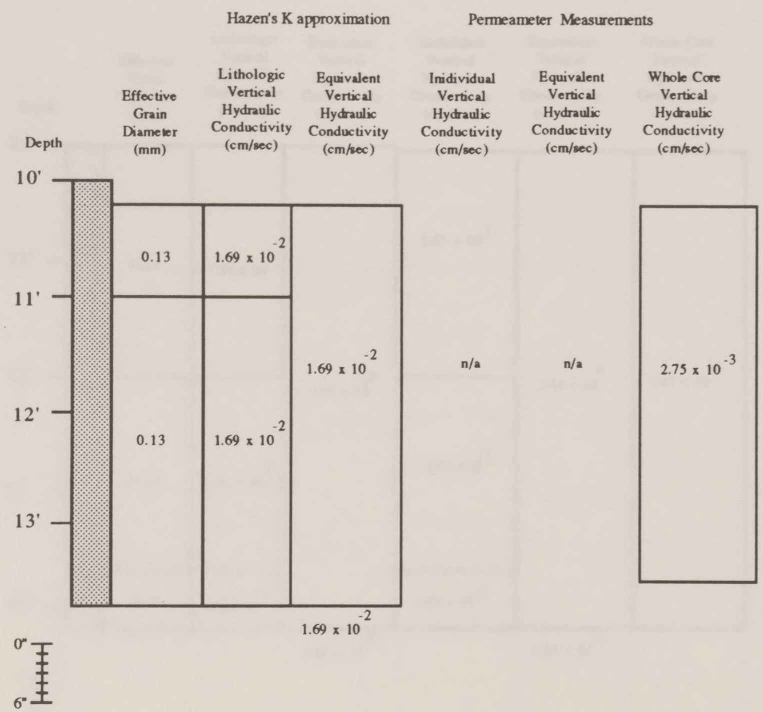
Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
Organics, no collection					
0.205	4.20×10^{-2}	7.27×10^{-3}	7.51×10^{-4}	1.28×10^{-5}	2.62×10^{-5}
0.12	1.44×10^{-2}		9.32×10^{-4}		
0.06	3.6×10^{-3}		5.00×10^{-6}		
		1.78×10^{-2}		5.24×10^{-4}	

Well Number : 019
Depth : 5-10 feet
Recovery : 40 inches

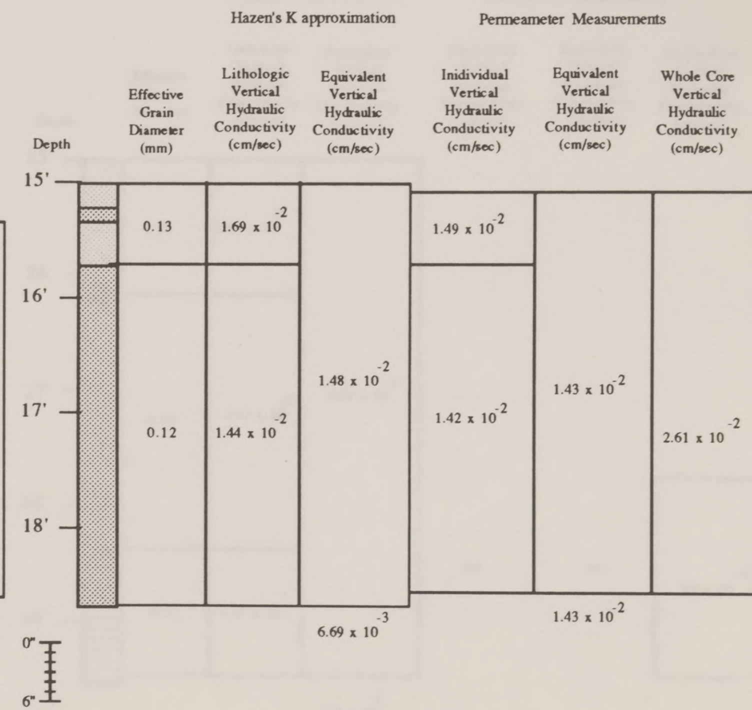


Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
0.28	7.84×10^{-2}	8.36×10^{-3}	1.40×10^{-4}	1.24×10^{-4}	1.92×10^{-4}
0.053	2.81×10^{-2}		4.53×10^{-4}		
0.21	4.41×10^{-2}		6.06×10^{-3}		
0.06	3.60×10^{-3}		4.70×10^{-5}		
		3.76×10^{-2}		8.57×10^{-3}	

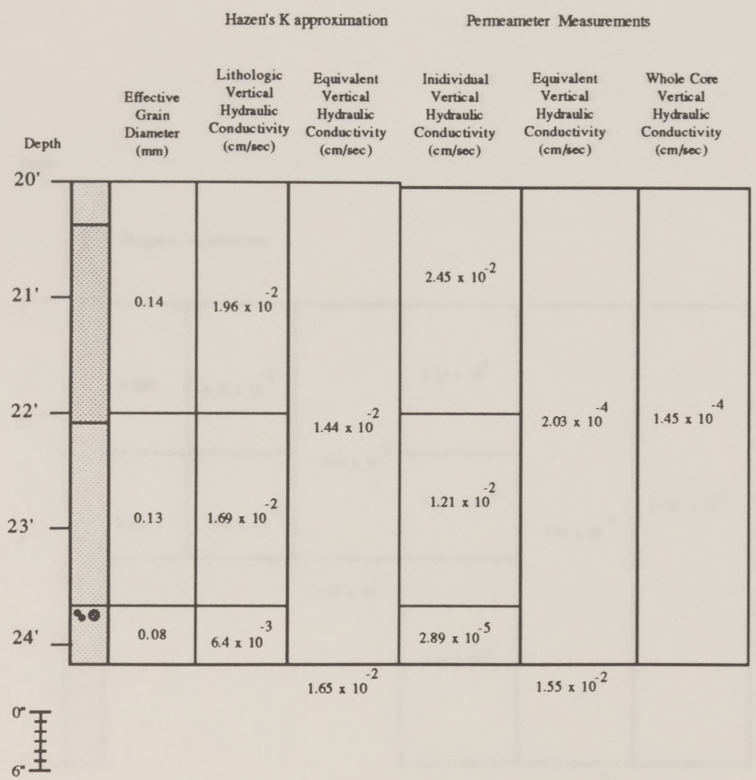
Well Number : 019
Depth : 10-15 feet
Recovery : 39 inches



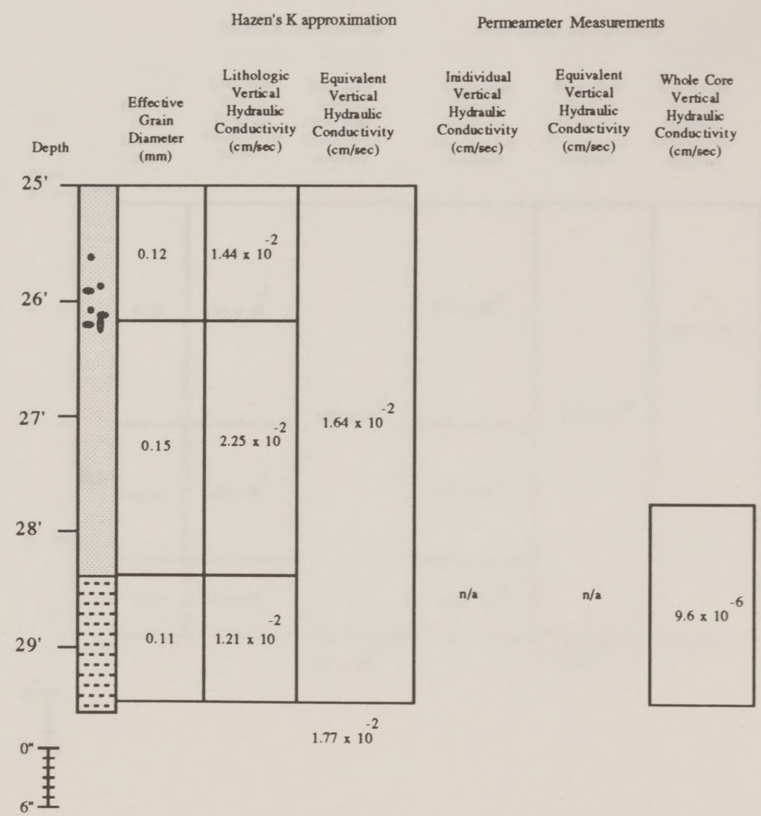
Well Number : 019
Depth : 15-20 feet
Recovery : 41.5 inches



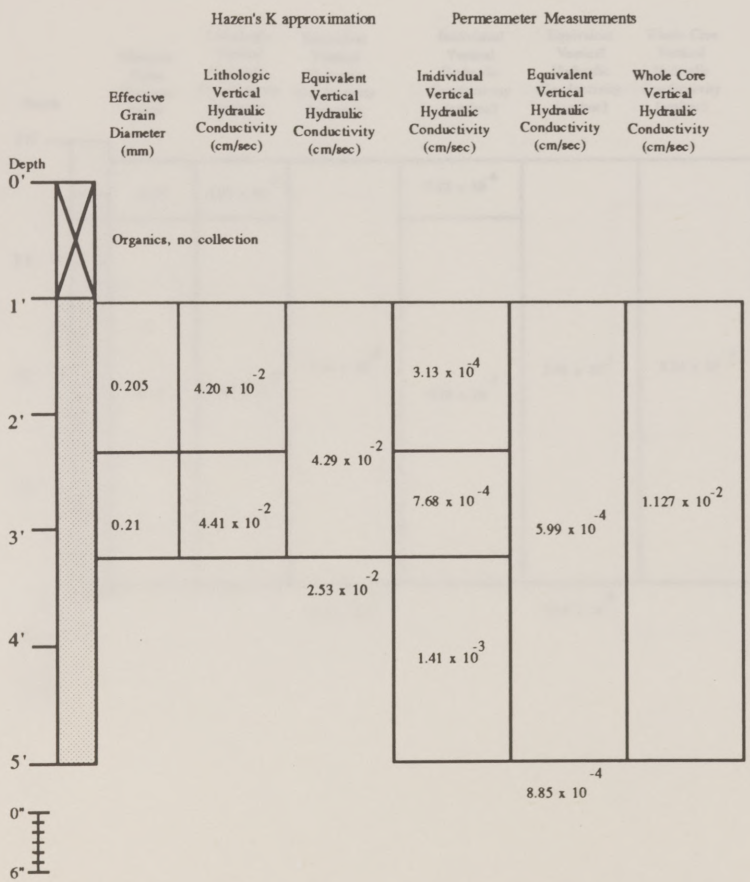
Well Number : 019
Depth : 20-25 feet
Recovery : 49.5 inches



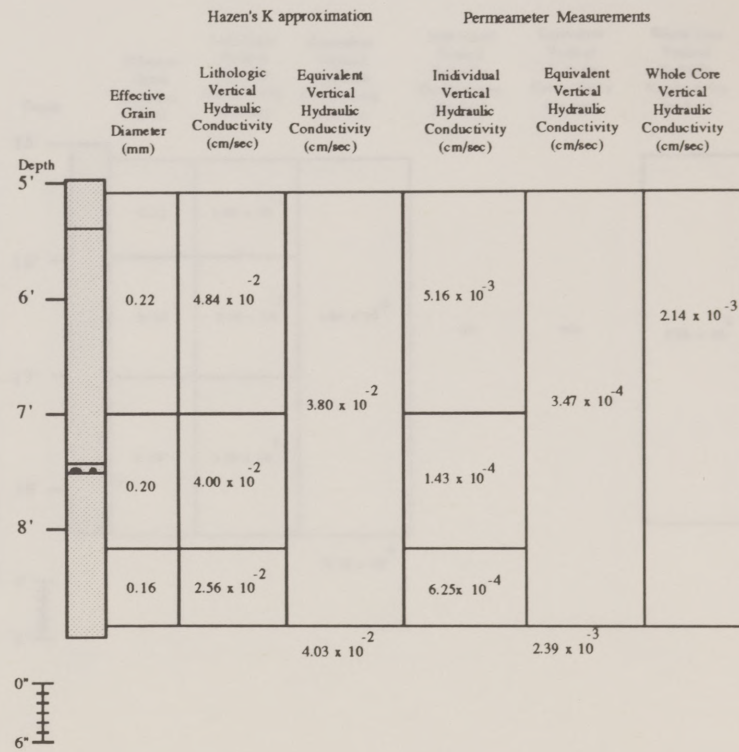
Well Number : 019
Depth : 25-30 feet
Recovery : 54.5 inches



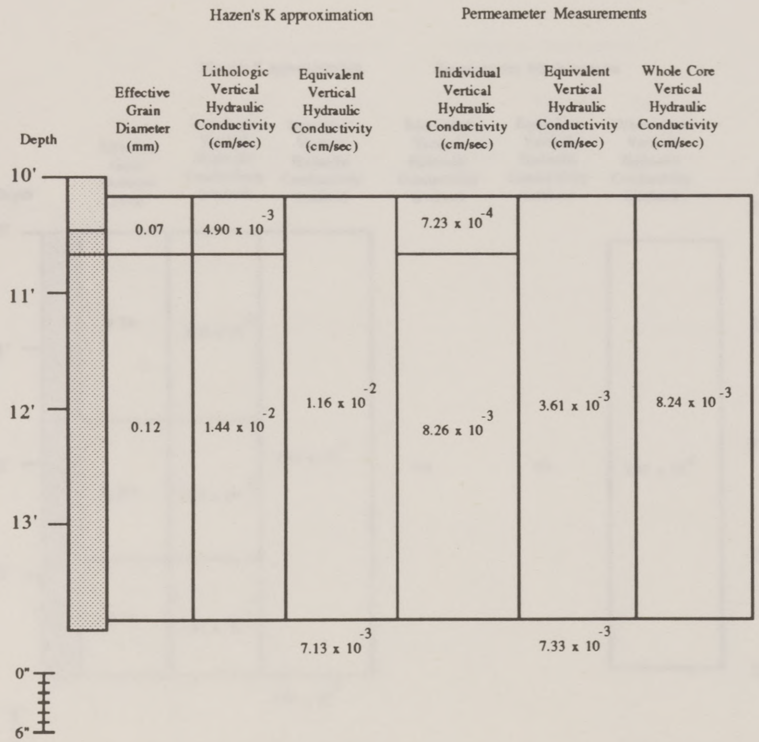
Well Number : 020
Depth : 0-5 feet
Recovery : 48.5 inches



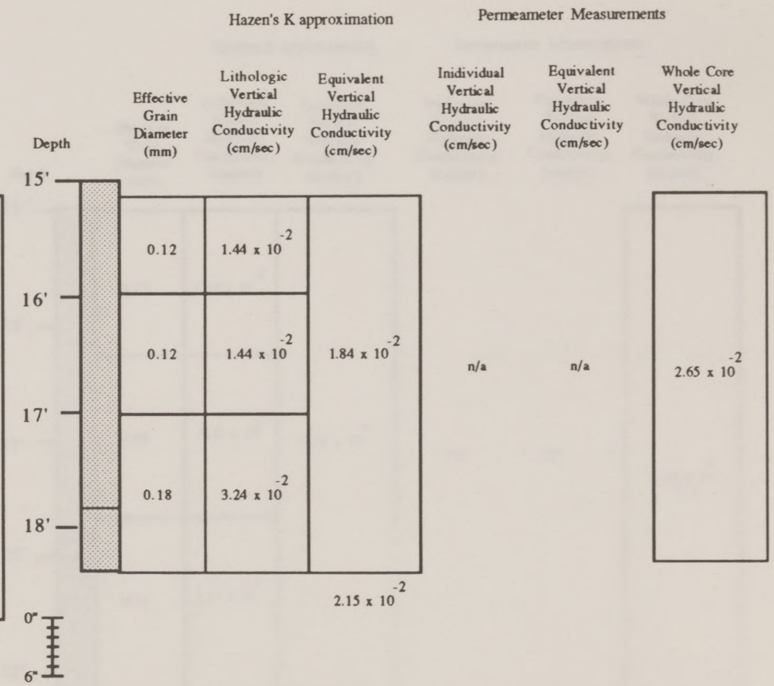
Well Number : 020
Depth : 5-10 feet
Recovery : 46.5 inches



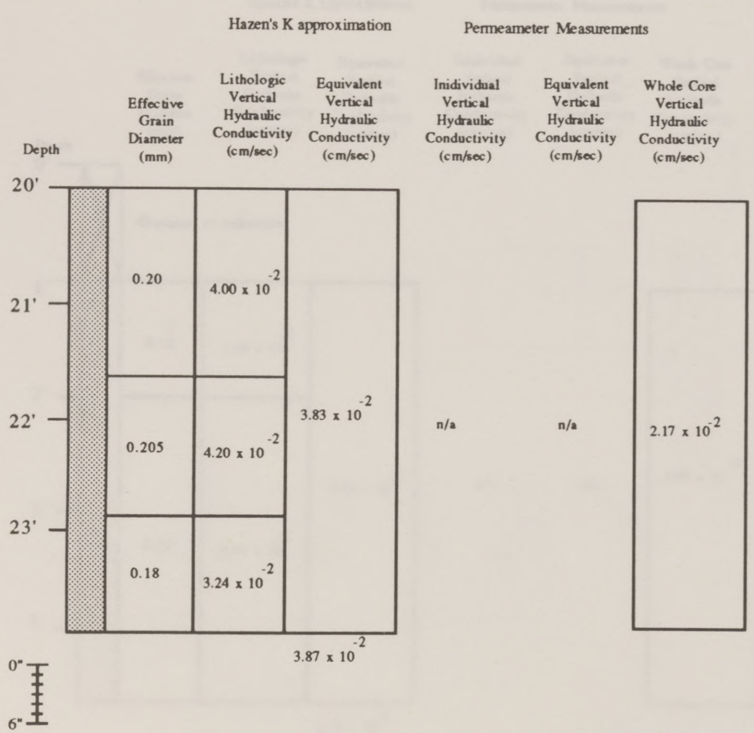
Well Number : 020
Depth : 10-15 feet
Recovery : 45 inches



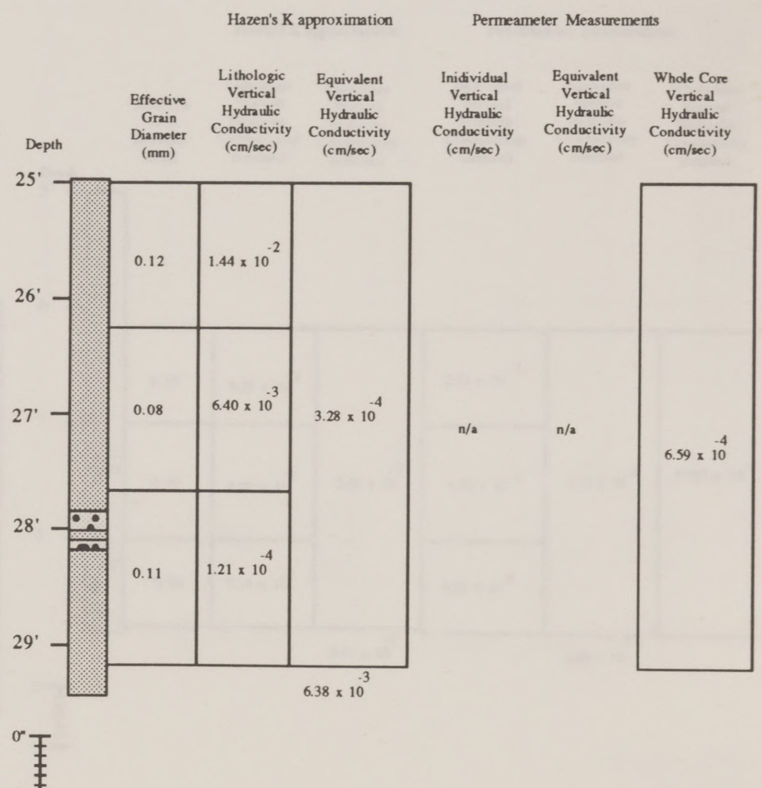
Well Number : 020
Depth : 15-20 feet
Recovery : 38 inches



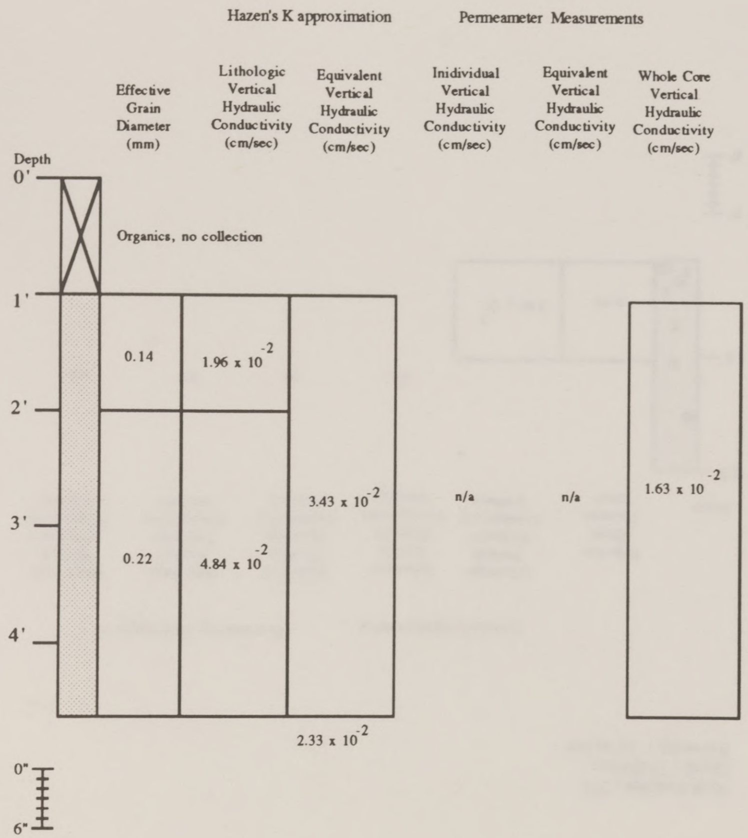
Well Number : 020
Depth : 20-25 feet
Recovery : 46 inches



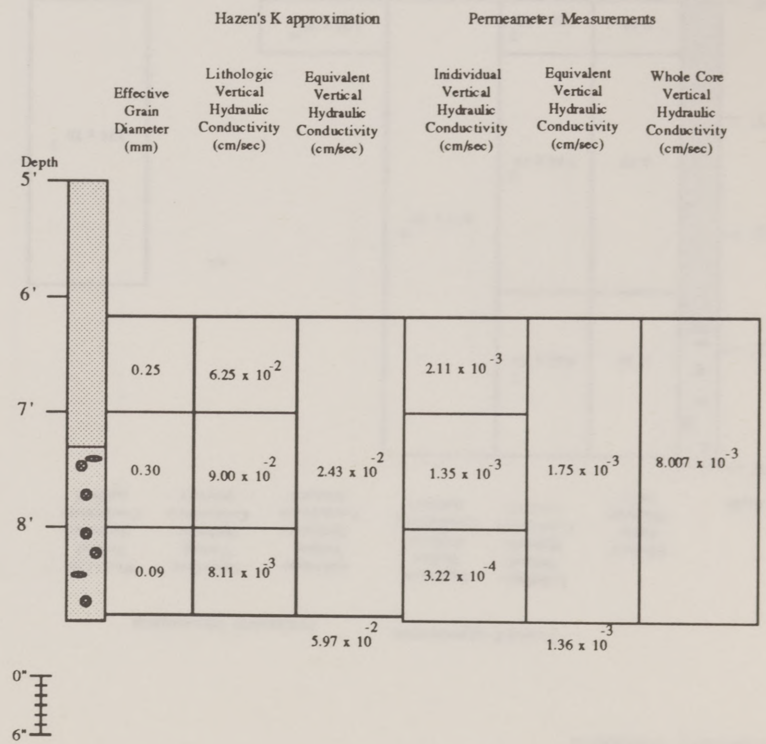
Well Number : 020
Depth : 25-30 feet
Recovery : 54 inches



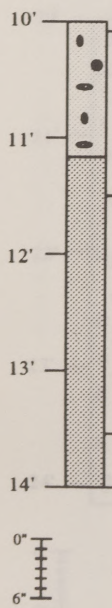
Well Number : 021
Depth : 0-5 feet
Recovery : 43 inches



Well Number : 021
Depth : 5-10 feet
Recovery : 31.5 inches

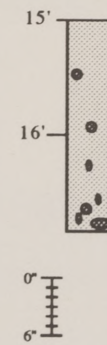


Well Number : 021
Depth : 10-15 feet
Recovery : 30.25 inches



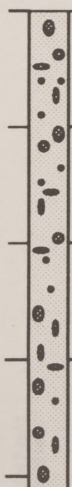
Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
10'–11'	0.30	9.00×10^{-2}	6.73×10^{-2}		n/a	2.74×10^{-3}
12'–13'	0.28	7.84×10^{-2}				
14'	0.18	3.24×10^{-2}		1.33×10^{-4}		
			7.57×10^{-2}			

Well Number : 021
Depth : 15-20 feet
Recovery : 12 inches



Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Inidividual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
15'–16'	0.19	3.61×10^{-2}	n/a	n/a	n/a	n/a

Well Number : 021
Depth : 20-25 feet
Recovery : 50 inches



Depth	Effective Grain Diameter (mm)	Hazen's K approximation: Lithologic Vertical Hydraulic Conductivity (cm/sec)	Hazen's K approximation: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Individual Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Equivalent Vertical Hydraulic Conductivity (cm/sec)	Permeameter Measurements: Whole Core Vertical Hydraulic Conductivity (cm/sec)
20' – 21'	0.28	7.84×10^{-2}	8.60×10^{-2}	n/a	n/a	2.46×10^{-2}
21' – 22'	0.37	1.37×10^{-1}				
22' – 23'	0.28	7.84×10^{-2}				
23' – 24'	0.27	7.29×10^{-2}				
			9.17×10^{-2}			

0"
6"

Appendix A6 Infiltration Measurements

IA = Infiltrometer ring area, 1850.7 cm^2
GA = Guelph reservoir area, 35.09 cm^2

	Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	 (m/d)	Location Mean (m/d)
Zone A						
Well 605---7/3/90	1	29.2	1024.6	0.55	7.97	8.04
	2	30.8	1080.8	0.58	8.41	
	3	27.6	968.5	0.52	7.54	
	4	23.96	840.8	0.45	6.54	
	5	34.1	1196.6	0.65	9.31	
	6	31.1	1091.3	0.59	8.49	
Grid H1---6/30/90	1	34.1	1196.6	0.65	9.31	13.16
	2	47.3	1659.8	0.90	12.91	
	3	52.7	1849.2	1.00	14.39	
	4	58.7	2059.8	1.11	16.03	
Grid B(-2)---7/1/90	1	24.6	863.2	0.47	6.72	8.28
	2	36.5	1280.8	0.69	9.97	
	3	26.3	922.9	0.50	7.18	
	4	28.1	986.0	0.53	7.67	
	5	35.9	1259.7	0.68	9.80	
	6	26.9	943.9	0.51	7.34	
	7	31.1	1091.3	0.59	8.49	
	8	26.9	943.9	0.51	7.34	
	9	29.9	1049.2	0.57	8.16	
	10	37.1	1301.8	0.70	10.13	
Grid I(-2)---6/28/90	1	18.8	659.7	0.36	5.13	8.21
	2	26.8	940.4	0.51	7.32	
	3	30.8	1080.8	0.58	8.41	
	4	33.6	1179.0	0.64	9.17	
	5	35.6	1249.2	0.67	9.72	
	6	36	1263.2	0.68	9.83	
	7	35.2	1235.2	0.67	9.61	
	8	23.6	828.1	0.45	6.44	
	9	23.2	814.1	0.44	6.33	
	10	29.6	1038.7	0.56	8.08	
	11	28	982.5	0.53	7.64	
	12	30	1052.7	0.57	8.19	
	13	30	1052.7	0.57	8.19	
	14	32	1122.9	0.61	8.74	
	15	36	1263.2	0.68	9.83	
	16	32	1122.9	0.61	8.74	
Well 701---6/27/90	1	33.2	1165.0	0.63	9.06	10.13
	2	42.8	1501.9	0.81	11.69	
	3	35.9	1259.7	0.68	9.80	
	4	47.9	1680.8	0.91	13.08	
	5	47.9	1680.8	0.91	13.08	
	6	28	982.5	0.53	7.64	
	7	38	1333.4	0.72	10.38	
	8	38.8	1361.5	0.74	10.59	
	9	42	1473.8	0.80	11.47	
	10	37.2	1305.3	0.71	10.16	
	11	48	1684.3	0.91	13.11	
	12	32	1122.9	0.61	8.74	
	13	23.9	838.7	0.45	6.53	
	14	26.9	943.9	0.51	7.34	
	15	31.2	1094.8	0.59	8.52	
	16	36.8	1291.3	0.70	10.05	
	17	40	1403.6	0.76	10.92	

For Zone A
Mean 9.03 m/d
Median 8.74 m/d
Mode 8.74 m/d
Range 6.3-13.1 m/d

	Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	 (m/d)	Location Mean (m/d)
Zone B						
Grid E1---6/28/90	1	17.8	624.6	0.34	4.86	4.06
	2	17.6	617.6	0.33	4.81	
	3	15.2	533.4	0.29	4.15	
	4	13.6	477.2	0.26	3.71	
Grid E(-1) continued	5	18.4	645.7	0.35	5.02	
	6	17.6	617.6	0.33	4.81	
	7	15.2	533.4	0.29	4.15	
	8	19.6	687.8	0.37	5.35	
	9	17.8	624.6	0.34	4.86	
	10	15.2	533.4	0.29	4.15	
	11	12.8	449.2	0.24	3.49	
	12	15.6	547.4	0.30	4.26	
	13	12.4	435.1	0.24	3.39	
	14	12	421.1	0.23	3.28	
	15	13.6	477.2	0.26	3.71	
	16	13.6	477.2	0.26	3.71	
	17	14.8	519.3	0.28	4.04	
	18	13.2	463.2	0.25	3.60	
	19	14.8	519.3	0.28	4.04	
	20	14.8	519.3	0.28	4.04	
	21	8.4	294.8	0.16	2.29	
	22	6.8	238.6	0.13	1.86	
	23	17.2	603.5	0.33	4.70	
	24	17.6	617.6	0.33	4.81	
	25	16.4	575.5	0.31	4.48	
	26	18.8	659.7	0.36	5.13	
	27	14.4	505.3	0.27	3.93	
	28	13.2	463.2	0.25	3.60	
	29	12.4	435.1	0.24	3.39	
Grid G(-4)---6/26/9	1	14.4	505.3	0.27	3.93	3.50
	2	12.5	438.6	0.24	3.41	
	3	17.2	603.5	0.33	4.70	
	4	14.6	512.3	0.28	3.99	
	5	13.6	477.2	0.26	3.71	
	6	16.2	568.5	0.31	4.42	
	7	13.2	463.2	0.25	3.60	
	8	12.5	438.6	0.24	3.41	
	9	12.8	449.2	0.24	3.49	
	10	11.6	407.0	0.22	3.17	
	11	14.4	505.3	0.27	3.93	
	12	13.2	463.2	0.25	3.60	
	13	12	421.1	0.23	3.28	
	14	11.6	407.0	0.22	3.17	
	15	14	491.3	0.27	3.82	
	16	12	421.1	0.23	3.28	
	17	13.2	463.2	0.25	3.60	
	18	11.2	393.0	0.21	3.06	
	19	14	491.3	0.27	3.82	
	20	13.2	463.2	0.25	3.60	
	21	14	491.3	0.27	3.82	
	22	12.4	435.1	0.24	3.39	
	23	12.8	449.2	0.24	3.49	
	24	12	421.1	0.23	3.28	
	25	12.2	428.1	0.23	3.33	
	26	12	421.1	0.23	3.28	
	27	11.2	393.0	0.21	3.06	
	28	12.6	442.1	0.24	3.44	
	29	11.2	393.0	0.21	3.06	
	30	11.2	393.0	0.21	3.06	
	31	13.2	463.2	0.25	3.60	
	32	12.4	435.1	0.24	3.39	
	33	11.2	393.0	0.21	3.06	
	34	12.4	435.1	0.24	3.39	
	35	10.8	379.0	0.20	2.95	
	36	12.4	435.1	0.24	3.39	
	37	11.6	407.0	0.22	3.17	
	38	14.8	519.3	0.28	4.04	

For Zone B
Mean 3.79 m/d
Median 3.6 m/d
Mode 3.6 m/d
Range 2.9-5.4 m/d

Zone C
Grid C9---7/4/90

Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	Infiltration Rate (m/d)	Location Mean (m/d)
1	24	842.2	0.46	6.55	6.01
2	21	736.9	0.40	5.73	
3	18	631.6	0.34	4.91	
4	25.7	901.8	0.49	7.02	
5	25.1	880.8	0.48	6.85	
6	22.2	779.0	0.42	6.06	
7	28.8	1010.6	0.55	7.86	
8	15.6	547.4	0.30	4.26	
9	16.8	589.5	0.32	4.59	
10	16.8	589.5	0.32	4.59	
11	20.3	712.3	0.38	5.54	
12	16.2	568.5	0.31	4.42	
13	21.6	757.9	0.41	5.90	
14	18.6	652.7	0.35	5.08	
15	19.7	691.3	0.37	5.38	
16	23.9	838.7	0.45	6.53	
17	21	736.9	0.40	5.73	
18	22.7	796.5	0.43	6.20	
19	23.9	838.7	0.45	6.53	
20	23.9	838.7	0.45	6.53	
21	23.9	838.7	0.45	6.53	
22	19.2	673.7	0.36	5.24	
23	25.7	901.8	0.49	7.02	
24	27	947.4	0.51	7.37	
25	19	666.7	0.36	5.19	
26	30	1052.7	0.57	8.19	
27	23.9	838.7	0.45	6.53	

Grid K4---7/4/90

Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	Infiltration Rate (m/d)	Location Mean (m/d)
1	16.2	568.5	0.31	4.42	5.98
2	17.4	610.6	0.33	4.75	
3	16.4	575.5	0.31	4.48	
4	20.4	715.8	0.39	5.57	
5	21.6	757.9	0.41	5.90	
6	21.6	757.9	0.41	5.90	
7	21.6	757.9	0.41	5.90	
8	19.2	673.7	0.36	5.24	
9	28.1	986.0	0.53	7.67	
10	19.7	691.3	0.37	5.38	
11	23.4	821.1	0.44	6.39	
12	22.8	800.1	0.43	6.23	
13	20.4	715.8	0.39	5.57	
14	21.6	757.9	0.41	5.90	
15	22.8	800.1	0.43	6.23	
16	22.8	800.1	0.43	6.23	
17	23.9	838.7	0.45	6.53	
18	22.2	779.0	0.42	6.06	
19	23.9	838.7	0.45	6.53	
20	25.6	898.3	0.49	6.99	
21	28.1	986.0	0.53	7.67	

For Zone C
Mean 5.79 m/d
Median 5.90 m/d
Mode 6.53 m/d
Range 4.3-7.0 m/d

Zone D
Grid D7---6/25/90

Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	Infiltration Rate (m/d)	Location Mean (m/d)
1	0.2	7.0	0.00	0.05	0.06
2	0.2	7.0	0.00	0.05	
3	0.2	7.0	0.00	0.05	
4	0.2	7.0	0.00	0.05	
5	0.2	7.0	0.00	0.05	
6	0.2	7.0	0.00	0.05	
7	0.225	7.9	0.00	0.06	
8	0.225	7.9	0.00	0.06	
9	0.2	7.0	0.00	0.05	
10	0.225	7.9	0.00	0.06	
11	0.2	7.0	0.00	0.05	
12	0.25	8.8	0.00	0.07	
13	0.25	8.8	0.00	0.07	
14	0.2	7.0	0.00	0.05	
15	0.25	8.8	0.00	0.07	
16	0.25	8.8	0.00	0.07	
17	0.2	7.0	0.00	0.05	
18	0.24	8.4	0.00	0.07	

Grid D7 continued

Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	Infiltration Rate (m/d)	Location Mean (m/d)
19	0.24	8.4	0.00	0.07	
20	0.2	7.0	0.00	0.05	
21	0.22	7.7	0.00	0.06	

Grid F7---6/25/90

Reading Number	a Water Level Change Rate (cm/min)	b Volume of Water Loss (a * GA) (cm^3/min)	Infiltration Rate (b / IA) (cm/min)	Infiltration Rate (m/d)	Location Mean (m/d)
1	0.2	7.0	0.00	0.05	0.04
2	0.1	3.5	0.00	0.03	
3	0.1	3.5	0.00	0.03	
4	0.125	4.4	0.00	0.03	
5	0.125	4.4	0.00	0.03	
6	0.15	5.3	0.00	0.04	
7	0.1	3.5	0.00	0.03	
8	0.2	7.0	0.00	0.05	
9	0.15	5.3	0.00	0.04	
10	0.2	7.0	0.00	0.05	
11	0.1	3.5	0.00	0.03	
12	0.2	7.0	0.00	0.05	
13	0.2	7.0	0.00	0.05	
14	0.15	5.3	0.00	0.04	
15	0.2	7.0	0.00	0.05	
16	0.2	7.0	0.00	0.05	
17	0.25	8.8	0.00	0.07	
18	0.2	7.0	0.00	0.05	
19	0.15	5.3	0.00	0.04	
20	0.15	5.3	0.00	0.04	
21	0.2	7.0	0.00	0.05	
22	0.15	5.3	0.00	0.04	

For Zone D
Mean 0.05 m/d
Median 0.05 m/d
Mode 0.05 m/d
Range 0-0.07 m/d

Appendix A7 Soil Survey

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
A(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
A(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
A(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
A(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
A(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
A(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
A01	1-7	9/5/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	
A02	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	
A04	0-6	9/4/90	buff-brown medium-coarse sand	cobbles, dead trees	sparse grasses	gentle-moderate	Yes	
A05	1-7	9/4/90	buff-brown medium-coarse sand	cobbles, dead trees	sparse grasses	gentle-moderate	No	0-3" loose soil 3-6" packed soil
A06	1-7	9/4/90	buff-brown medium-coarse sand	cobbles, dead trees	sparse grasses	Yes	Yes	
A10	2-8	9/4/90	orange-brown fine-medium sand	dead grass/limbs	sparse tall grasses, moss, 2 ft. pines, 3 ft. bushes	flat-gentle to northeast	No	Rooting
B(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
B(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
B(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
B(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
B(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
B(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
B01	1-7	9/5/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, 2 ft. grass, 3 ft. pines	gentle-moderate to northeast	No	Some rooting
B02	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, 2 ft. grass, 3 ft. pines	gentle-moderate to northeast	No	Some rooting
B03	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	moss, few pines, grass	gentle to northeast	No	Lots of rooting
B04	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	grasses, few 2 ft. pines	gentle	No	
B05	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	grasses, few 2 ft. pines	none	No	
B06	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	grasses, few 2 ft. pines	none	No	
B07	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	moss, grass, 2 ft. pines	moderate	No	Lots of rooting
B09	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, dead grasses/trees	moss, grass, 2 ft. pines	gentle to southwest	No	Lots of rooting
B10	2-8	9/4/90	gray-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	moss, grass, 2 ft. pines	gentle to northeast	No	
B11	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
C(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
C(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
C(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
C(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
C(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
C(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
C02	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, 2 ft. grass, 3 ft. pines	gentle-moderate to northeast	No	Some rooting

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
C03	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	moss, few pines, grass	gentle to northeast	No	Lots of rooting
C04	0-6	9/4/90	orange-brown medium sand	pebbles, cobbles, dead grass	1-2 ft. pines, sparse grass	gentle to northeast	No	
C05	0-6	9/4/90	orange-brown medium sand	pebbles, cobbles, dead grass	1-2 ft. pines, sparse grass	gentle to northeast	No	
C06	1-7	9/4/90	brown medium coarse sand with pebbles	pebbles, dead grass	moss, 2ft. grasses	gentle to north	No	
C07	1-7	9/4/90	brown medium coarse sand with pebbles	pebbles, dead grass	moss, 2ft. grasses	gentle to north	No	
C08	2-8	9/4/90	gray-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	moss, grass, 2 ft. pines	gentle to northeast	No	
C09	2-8	9/4/90	gray-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	moss, grass, 2 ft. pines	gentle to northeast	No	
C10	2-8	9/4/90	gray-brown medium-coarse sand	pebbles, cobbles, dead grass/trees	moss, grass, 2 ft. pines	gentle to northeast	No	
C11	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
D(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
D(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
D(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
D(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
D(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
D02	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, 2 ft. grass, 3 ft. pines	gentle-moderate to northeast	No	Some rooting
D03	1-7	9/4/90	orange-brown medium-coarse sand	pebbles, cobbles, dead grass	moss, few pines, grass	gentle to northeast	No	Lots of rooting
D04	0-6	9/4/90	buff brown medium-coarse sand	pebbles, cobbles	barren, few grasses	flat	Yes	0-3" loose soil
D05	0-6	9/4/90	orange-brown medium sand	pebbles, cobbles, dead grass	1-2 ft. pines, sparse grass	gentle to northeast	No	3-6" packed soil

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
D06	1-7	9/4/90	brown medium coarse sand with pebbles	pebbles, cobbles, dead grass	moss, 2ft. grasses	gentle to north	No	
D07	0-6	9/4/90	brown-black medium-coarse sand	pebbles, cobbles	none	gentle to southwest	Yes	
D08	0-6	9/4/90	buff-orange medium-coarse sand	pebbles, dead limbs	sparse grasses, bushes, 2 ft. pines	gentle to southwest	No	Soil plowed loose
D08	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, dead grass/trees	moss, grass, 2 ft. pines	variable-hilltop	No	Lots of rooting
D09	0-6	9/4/90	buff-orange medium-coarse sand	pebbles, dead limbs	sparse grasses, bushes, 2 ft. pines	gentle to southwest	No	Soil plowed loose
E(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
E(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
E(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
E(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
E(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
E02	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, 2 ft. grass, 3 ft. pines	gentle-moderate to northeast	No	Some rooting
E03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
E04	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil
E05	0-6	9/4/90	brown-black medium-coarse sand	pebbles, cobbles	none	gentle to southwest	Yes	2-6" packed soil
E06	0-6	9/4/90	brown-black medium-coarse sand	pebbles, cobbles	none	gentle to southwest	Yes	
E07	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
E08	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, dead grass/trees	moss, grass, 2 ft. pines	none to gentle	No	Lots of rooting
E09	1-7	9/4/90	buff-brown medium-coarse sand	pebbles, dead grass/trees	moss, grass, 2 ft. pines	gentle to southwest	No	Lots of rooting

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
F(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass	moss, grass, bushes	gentle to southwest	No	Lots of rooting
F(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
F(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
F(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
F(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
F(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
F(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 10-20 ft. pines	variable	No	Lots of rooting
F01	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, lots of 2 ft. grass, 3 ft. pines	gentle-moderate to northeast	No	
F02	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, cobbles, dead grass	moss, 2 ft. grasses/bushes, few pines	gentle-moderate to northeast	No	
F03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
F04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
F05	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
F06	0-6	9/4/90	brown-black medium-coarse sand	pebbles, cobbles	None	gentle to southwest	Yes	
F07	0-6	9/4/90	brown medium-coarse sand	None	None	gentle to southwest	Yes	Very loose soil
F08	0-6	9/4/90	brown medium-coarse sand	None	None	gentle to southwest	Yes	Very loose soil
F09	2-8	9/4/90	gray fine-coarse loamy sand	dead grass/trees	sparse grass, 3 ft. bushes 20 ft. pines	flat-gentle	No	Rooting
F10	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes 20 ft. pines	flat-gentle	No	Rooting
G(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
G(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
G(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
G(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
G(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
G(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
G01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
G02	1-7	9/5/90	brown fine-medium sand	dead grass	grass, bushes, trees	flat-gentle to wetland	No	Lots of rooting
G03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, few pines	moderate to southwest	No	Lots of rooting
G04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, lots of 2 ft. grasses and bushes, pines	moderate to southwest	No	
G05	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, lots of 2 ft. grasses and bushes, pines	moderate to southwest	No	
G06	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
G07	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
G08	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
G08	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
G09	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
G09	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	gentle to southwest	No	
H(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
H(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass	moss, grass, bushes	gentle to southwest	No	Lots of rooting
H(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
H(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
H(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
H(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
H(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
H01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
H02	1-7	9/5/90	buff-brown fine-medium sand	dead grass	moss, bushes	moderate	No	
H03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
H04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
H05	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
H06	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
H07	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
H08	0-6	9/4/90	brown-orange medium-coarse sand	trees, pebbles	sparse trees, grasses	gentle	Yes	0-2"loose soil 2-6" packed soil
H09	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
I(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
I(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass	moss, grass, bushes	gentle to southwest	No	Lots of rooting
I(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
I(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
I(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
I(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
I-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
I01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
I02	0-6	9/5/90	buff-brown fine-medium sand	dead grass	moss, bushes	moderate	Yes	
I03	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	
I04	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	
I05	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	
I06	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, dead grass	sparse grasses/bushes	gentle to wetland	No	
I07	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, dead grass	sparse grasses/bushes	gentle to wetland	No	
I08	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, dead grass	sparse grasses/bushes	gentle to wetland	No	
I09	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
J(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
J(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
J(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
J(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
J(-05)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
J(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
J01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
J02	0-6	9/5/90	buff-brown fine-medium sand	dead grass	moss, bushes	moderate	Yes	
J03	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
J04	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	
J05	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	
J06	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	1 ft. grass, 3 ft. pines	gentle to northeast	No	
J07	1-7	9/4/90	buff brown medium-coarse sand with pebbles	pebbles, cobbles, dead grass	grass, bushes, trees	moderate to wetland	Some	
J08	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
K(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
K(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
K(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
K(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
K(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
K(-06)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
K01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
K02	1-7	9/5/90	fine-medium sand fine-medium sand	dead grass	moss, bushes	moderate	No	
K03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
K04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
K04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
K05	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
K06	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	
K07	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	
K08	2-8	9/4/90	gray fine-coarse sand	dead grass/trees	sparse grass, 3 ft. bushes, 20 ft. pines	flat-gentle	No	Rooting
L(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
L(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
L(-03)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
L(-04)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	lots of dead grass/trees	moss, grass, bushes, 50 ft. pines	variable	No	Lots of rooting
L01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
L02	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
L03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
L04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
L05	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
L06	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
L07	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses/bushes, few pines	moderate to southwest	No	Lots of rooting
M(-01)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
M(-02)	2-8	9/5/90	buff-gray brown to orange fine-medium sand	dead grass/trees	moss, grass, bushes, 10-20 ft. pines	gentle to southwest	No	Lots of rooting
M01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
M02	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
M03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	
M04	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	

Location	Sample Depth (inches)	Date	Texture	Ground Cover Type	Vegetative Cover Type	Slope	Oil on surface	Comments
M05	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, 2 ft. grasses and bushes, pines	moderate to southwest	No	
M06	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting
M07	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting
M08	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting
N01	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
N02	2-8	9/5/90	brown fine-medium sand	dead trees/grass	moss, grass, 20 ft. trees	moderate to wetland	No	Lots of rooting
N03	1-7	9/4/90	brown-orange medium-coarse sand	dead grass/trees	moss, lots of 2 ft. grasses and bushes, pines	moderate to southwest	No	
N04	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting
N05	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting
N06	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting
N07	1-7	9/4/90	buff brown-gray fine-medium sand	pebbles, dead grass	moss, bushes, grass, trees	moderate to wetland	No	Rooting

Appendix A8.1 Percent organic carbon of oily samples

Sample Location	Before heating			After initial heating at 120° C overnight/dried in dessicator			After heating at 550° C for 2.5 hours/dried in desicator			10 Adjusted Total organic carbon per gm soil (for mapping) 9*(75%)
	1 Tare weight	2 Tare weight & moist soil	3 Moist soil weight (2-1)	4 Tare weight & dried soil	5 Dried soil weight (4-1)	6 Amount water released (2-4)	7 Tare weight & heated soil	8 Heated soil weight (7-1)	9 Total organic carbon per gm soil (4-7)/5*100	
	gms	gms	gms	gms	gms	gms	gms	gms	% by weight	% by weight
1I	10.3156	11.3209	1.0053	11.3166	1.001	0.0043	11.2981	0.9825	1.848	1.386
1J	10.7289	11.7334	1.0045	11.7309	1.002	0.0025	11.714	0.9851	1.687	1.265
2H	10.3165	11.5676	1.2511	11.5633	1.2468	0.0043	11.5336	1.2171	2.382	1.787
2I	10.8474	11.8465	0.9991	11.8408	0.9934	0.0057	11.8152	0.9678	2.577	1.933
2J	10.4413	11.4477	1.0064	11.445	1.0037	0.0027	11.4297	0.9884	1.524	1.143
2K	10.5136	11.6647	1.1511	11.6616	1.148	0.0031	11.6469	1.1333	1.280	0.960
3C	10.7281	11.6893	0.9612	11.685	0.9569	0.0043	11.6729	0.9448	1.264	0.948
3D	10.5751	11.8721	1.297	11.8673	1.2922	0.0048	11.851	1.2759	1.261	0.946
3E	10.4779	11.4785	1.0006	11.4738	0.9959	0.0047	11.4474	0.9695	2.651	1.988
3F	10.3582	11.3605	1.0023	11.3555	0.9973	0.005	11.329	0.9708	2.657	1.993
3I	10.4169	11.425	1.0081	11.4238	1.0069	0.0012	11.401	0.9841	2.264	1.698
3J	10.671	11.6728	1.0018	11.672	1.001	0.0008	11.663	0.992	0.899	0.674
4A	10.5744	11.7026	1.1282	11.6977	1.1233	0.0049	11.6739	1.0995	2.119	1.589
4C	10.4166	11.3347	0.9181	11.3293	0.9127	0.0054	11.321	0.9044	0.909	0.682
4D	10.8505	12.1834	1.3329	12.1818	1.3313	0.0016	12.1683	1.3178	1.014	0.761
4E	9.9561	10.9598	1.0037	10.9528	0.9967	0.007	10.924	0.9679	2.890	2.167
4F	10.8464	11.842	0.9956	11.8391	0.9927	0.0029	11.8239	0.9775	1.531	1.148
4G	10.8473	12.4866	1.6393	12.4808	1.6335	0.0058	12.4577	1.6104	1.414	1.061
5A	10.8494	11.833	0.9836	11.8271	0.9777	0.0059	11.8051	0.9557	2.250	1.688
5B	10.3157	11.35	1.0343	11.3443	1.0286	0.0057	11.3209	1.0052	2.275	1.706
5C	10.0584	11.3506	1.2922	11.3474	1.289	0.0032	11.3384	1.28	0.698	0.524
5D	10.4417	12.2812	1.8395	12.2714	1.8297	0.0098	12.2424	1.8007	1.585	1.189
5E	10.5135	11.5217	1.0082	11.5075	0.994	0.0142	11.481	0.9675	2.666	1.999
5F	10.4404	11.4416	1.0012	11.4396	0.9992	0.002	11.4307	0.9903	0.891	0.668
5G	9.9572	11.551	1.5938	11.5437	1.5865	0.0073	11.5069	1.5497	2.320	1.740
5H	10.4169	11.77	1.3531	11.7645	1.3476	0.0055	11.741	1.3241	1.744	1.308
6A	10.3574	11.3778	1.0204	11.3711	1.0137	0.0067	11.3453	0.9879	2.545	1.909
6B	10.241	11.0895	0.8485	11.0851	0.8441	0.0044	11.0631	0.8221	2.606	1.955
6C	10.479	11.4106	0.9316	11.4062	0.9272	0.0044	11.3864	0.9074	2.135	1.602
6D	10.5748	12.4527	1.8779	12.4436	1.8688	0.0091	12.4124	1.8376	1.670	1.252
6E	10.2417	11.2438	1.0021	11.2391	0.9974	0.0047	11.2136	0.9719	2.557	1.917
6F	10.5738	11.574	1.0002	11.5664	0.9926	0.0076	11.5307	0.9569	3.597	2.697
6G	10.6721	13.6028	2.9307	13.5899	2.9178	0.0129	13.5061	2.834	2.872	2.154
6H	10.1401	12.054	1.9139	12.0464	1.9063	0.0076	12.0073	1.8672	2.051	1.538
6I	10.242	11.2573	1.0153	11.2526	1.0106	0.0047	11.2328	0.9908	1.959	1.469
6J	10.5128	11.5163	1.0035	11.5155	1.0027	0.0008	11.5043	0.9915	1.117	0.838
7B	10.4004	11.5666	1.1662	11.5573	1.1569	0.0093	11.5198	1.1194	3.241	2.431
7C	10.4422	11.3669	0.9247	11.3651	0.9229	0.0018	11.354	0.9118	1.203	0.902
7D	10.0586	12.3269	2.2683	12.3113	2.2527	0.0156	12.2001	2.1415	4.936	3.702
7E	10.4002	11.4015	1.0013	11.3966	0.9964	0.0049	11.3557	0.9555	4.105	3.079
7F	10.6711	11.6705	0.9994	11.6672	0.9961	0.0033	11.6443	0.9732	2.299	1.724
7G	10.7295	12.8127	2.0832	12.8037	2.0742	0.009	12.7555	2.026	2.324	1.743
7H	10.5134	12.6071	2.0937	12.599	2.0856	0.0081	12.5378	2.0244	2.934	2.201
7I	10.3578	11.3578	1	11.354	0.9962	0.0038	11.3297	0.9719	2.439	1.829
7J	9.9561	10.9622	1.0061	10.9603	1.0042	0.0019	10.9466	0.9905	1.364	1.023
8C	10.4172	11.4281	1.0109	11.4221	1.0049	0.006	11.3977	0.9805	2.428	1.821
8D	10.2418	11.2484	1.0066	11.2416	0.9998	0.0068	11.2082	0.9664	3.341	2.506
8E	10.7298	11.731	1.0012	11.7211	0.9913	0.0099	11.6679	0.9381	5.367	4.025
8F	10.8516	11.9823	1.1307	11.9788	1.1272	0.0035	11.9445	1.0929	3.043	2.282
8G	10.4775	12.026	1.5485	12.0194	1.5419	0.0066	11.993	1.5155	1.712	1.284
8H	10.1415	11.7131	1.5716	11.7069	1.5654	0.0062	11.6775	1.536	1.878	1.409
8I	10.1385	11.1452	1.0067	11.1419	1.0034	0.0033	11.1225	0.984	1.933	1.450
8J	10.477	11.4861	1.0091	11.4026	0.9256	0.0835	11.3868	0.9098	1.707	1.280
9F	10.3157	11.3154	0.9997	11.3092	0.9935	0.0062	11.2716	0.9559	3.785	2.838
9G	10.4011	12.2909	1.8898	12.2803	1.8792	0.0106	12.2401	1.839	2.139	1.604
9H	10.3591	11.4673	1.1082	11.4594	1.1003	0.0079	11.4275	1.0684	2.899	2.174
9I	10.5741	11.5811	1.007	11.577	1.0029	0.0041	11.5524	0.9783	2.453	1.840
							Minimum		0.698	0.524
							Maximum		5.367	4.025
							Mean		2.232	1.674
							Median		2.250	1.688
							Standard Deviation		0.943	0.707

Appendix A8.2 Percent organic carbon of non-oily samples

	Before heating		After initial heating at 120°C overnight/dried in dessicator		After adding 1% phosphoric acid (PA) & vacuum & drying for 2.5 hours at 120°C			Dohrmann Analyzer results			
Sample Location	1 Tare weight gms	2 Tare weight & moist soil gms	3 Tare weight & dried soil gms	4 Dried soil weight (3-1) gms	5 Tare weight & PA & dried soil gms	6 Dried soil & PA (5-1) gms	7 Inorganic carbon per gm soil (3-5)/4*100 % by weight	8 Total organic carbon ppm Carbon	9 Standard Deviation %	10 Organic carbon per gm soil (6/4*8/10000) % by weight	Total organic carbon (10+7) % by weight
(-6A)	27.8196	28.9398	28.9310	1.1114	28.9294	1.1098	0.144	4358.6	12.51	0.435	0.579
(-6F)	29.1560	30.3689	30.3648	1.2088	30.3454	1.1894	1.605	4583.1	7.495	0.451	2.056
(-6H)	28.3985	29.3357	29.3322	0.9337	29.3271	0.9286	0.546	4281.3	7.811	0.426	0.972
(-6J)	27.8315	29.0591	29.0528	1.2213	29.0510	1.2195	0.147	2226.8	13.73	0.222	0.370
(-5A)	30.0469	31.6007	31.5939	1.5470	31.5927	1.5458	0.078	3426.9	39.58	0.342	0.420
(-5C)	29.1578	30.7656	30.7582	1.6004	30.7519	1.5941	0.394	4249.6	22.8	0.423	0.817
(-5E)	28.3952	29.3345	29.3294	0.9342	29.3273	0.9321	0.225	10001.0	32.31	0.998	1.223
(-5G)	29.4665	30.5877	30.5802	1.1137	30.5782	1.1117	0.180	4526.2	27.27	0.452	0.631
(-5I)	28.2143	29.1736	29.1707	0.9564	29.1674	0.9531	0.345	5060.2	26.61	0.504	0.849
(-4B)	28.4863	29.3618	29.3580	0.8717	29.3567	0.8704	0.149	4353.0	22.14	0.435	0.584
(-4D)	27.2613	28.4612	28.4520	1.1907	28.4480	1.1867	0.336	13047.0	43.53	1.300	1.636
(-4F)	30.0513	31.5041	31.4955	1.4442	31.4887	1.4374	0.471	2325.6	30.06	0.231	0.702
(-4H)	27.2693	28.2531	28.2487	0.9794	28.2461	0.9768	0.265	6082.2	7.588	0.607	0.872
(-4J)	27.6526	29.2758	29.2646	1.6120	29.2636	1.6110	0.062	5242.9	21.33	0.524	0.586
(-4L)	28.2127	29.4618	29.4557	1.2430	29.4532	1.2405	0.201	4104.0	22.39	0.410	0.611
(-3A)	29.1382	30.3315	30.3231	1.1849	30.3209	1.1827	0.186	9842.3	17	0.982	1.168
(-3C)	28.2186	28.8931	28.8861	0.6675	28.8853	0.6667	0.120	13397.0	20.95	1.338	1.458
(-3E)	27.6532	28.5566	28.5535	0.9003	28.5506	0.8974	0.322	3138.1	25.92	0.313	0.635
(-3G)	29.4638	30.8276	30.8243	1.3605	30.8226	1.3588	0.125	2489.5	37.2	0.249	0.374
(-3I)	30.0507	31.0290	31.0265	0.9758	31.0240	0.9733	0.256	1086.4	9.136	0.108	0.365
(-3K)	27.6536	28.9813	28.9760	1.3224	28.9727	1.3191	0.250	6779.9	29.27	0.676	0.926
(-2B)	29.4683	30.7554	30.7521	1.2838	30.7474	1.2791	0.366	2753.7	17.44	0.274	0.640
(-2D)	29.4648	30.1787	30.1747	0.7099	30.1687	0.7039	0.845	9825.3	22.03	0.974	1.819
(-2F)	28.2107	29.3374	29.3327	1.1220	29.3309	1.1202	0.160	3654.7	49.73	0.365	0.525
(-2H)	29.6265	30.7534	30.7467	1.1202	30.7436	1.1171	0.277	5687.7	34.82	0.567	0.844
(-2J)	27.2663	28.1213	28.1197	0.8534	28.1171	0.8508	0.305	3326.3	37.46	0.332	0.636
(-2L)	27.8209	28.6790	28.6737	0.8528	28.6702	0.8493	0.410	4084.8	26	0.407	0.817
(-1A)	28.3824	29.5949	29.5878	1.2054	29.5859	1.2035	0.158	4349.0	13.2	0.434	0.592
(-1C)	29.1561	28.9858	29.9824	0.8263	29.9798	0.8237	0.315	5976.0	11.53	0.596	0.910
(-1E)	28.4668	29.3528	29.3472	0.8804	29.3445	0.8777	0.307	3954.1	55.79	0.394	0.701
(-1G)	29.4672	30.8057	30.8010	1.3338	30.7978	1.3306	0.240	4234.1	21.85	0.422	0.662
(-1I)	28.4860	29.3794	29.3764	0.8904	29.3745	0.8885	0.213	4240.2	18.82	0.423	0.637
(-1K)	29.4648	30.4133	30.4034	0.9386	30.4029	0.9381	0.053	5539.4	16.58	0.554	0.607
1A	27.8189	28.8904	28.8872	1.0683	28.8823	1.0634	0.459	5520.3	-	0.549	1.008
1B	28.2105	29.6610	29.6570	1.4465	29.6516	1.4411	0.373	1525.3	22.71	0.152	0.525
1D	29.1617	30.3808	30.3741	1.2124	30.3714	1.2097	0.223	2560.0	12.78	0.255	0.478
1F	29.6269	31.3130	31.3088	1.6819	31.3060	1.6791	0.166	2899.1	9.914	0.289	0.456
1G	28.2013	29.5345	29.5241	1.3228	29.5226	1.3213	0.113	9242.1	11.37	0.923	1.037
1L	29.1558	30.2505	30.2432	1.0874	30.2420	1.0862	0.110	5133.8	14.09	0.513	0.623
2B	27.2617	28.5031	28.5005	1.2388	28.4983	1.2366	0.178	1215.2	12.25	0.121	0.299
2C	27.6527	29.2300	29.2273	1.5746	29.2231	1.5704	0.267	6261.2	29.22	0.624	0.891
2E	27.6746	29.5350	29.5255	1.8509	29.5238	1.8492	0.092	3429.8	41.24	0.343	0.435
2G	30.0422	30.8488	30.8440	0.8018	30.8421	0.7999	0.237	7556.3	24.69	0.754	0.991
2M	28.3968	29.5140	29.5086	1.1118	29.5073	1.1105	0.117	3898.1	51.15	0.389	0.506
3L	29.6229	31.2279	31.2230	1.6001	31.2191	1.5962	0.244	4581.2	40.12	0.457	0.701
3G	28.4869	29.3941	29.3876	0.9007	29.3847	0.8978	0.322	6780.0	13.97	0.676	0.998
3N	27.6529	29.1318	29.1280	1.4751	29.1216	1.4687	0.434	3347.6	14.3	0.333	0.767
4B	29.6308	30.7349	30.7282	1.0974	30.7231	1.0923	0.465	8735.5	40.42	0.869	1.334
4H	27.8596	29.4164	29.4119	1.5523	29.4060	1.5464	0.380	3804.3	32	0.379	0.759
4J	28.4851	29.7479	29.7445	1.2594	29.7424	1.2573	0.167	6760.7	51.49	0.675	0.842
4K	28.2095	29.5253	29.5225	1.3130	29.5211	1.3116	0.107	4115.7	15.24	0.411	0.518
4M	27.8307	30.1155	30.1101	2.2794	30.1062	2.2755	0.171	1266.1	15.62	0.126	0.297
5J	28.3964	29.3663	29.3634	0.9670	29.3579	0.9615	0.569	5154.4	43.71	0.513	1.081
5L	27.2640	28.6269	28.6227	1.3587	28.6027	1.3387	1.472	1796.9	18.57	0.177	1.649
5N	27.2675	28.0079	28.0056	0.7381	28.0028	0.7353	0.379	4097.1	23.48	0.408	0.788
6K	28.4892	29.8992	29.8961	1.4069	29.8911	1.4019	0.355	1159.0	4.774	0.115	0.471
6M	29.6202	30.4796	30.4718	0.8516	30.4700	0.8498	0.211	6837.7	14.91	0.682	0.894
7K	30.0497	31.0870	31.0843	1.0346	31.0832	1.0335	0.106	4676.0	7.574	0.467	0.573
7L	29.4700	30.6505	30.6444	1.1744	30.6430	1.1730	0.119	2199.1	17.98	0.220	0.339
7N	29.4663	30.6703	30.6657	1.1994	30.6649	1.1986	0.067	6329.8	18.19	0.633	0.699
8M	29.6205	30.5676	30.5635	0.9430	30.5619	0.9414	0.170	3014.2	15.64	0.301	0.471
8B	30.0571	31.4851	31.4794	1.4223	31.4787	1.4216	0.049	777.6	21.53	0.078	0.127
8K	27.2705	28.0720	28.0664	0.7959	28.0661	0.7956	0.038	6662.7	30.78	0.666	0.704
9B	28.3954	30.5810	30.5775	2.1821	30.5694	2.1740	0.371	2317.9	42.68	0.231	0.602
9D	28.4904	30.3179	30.3112	1.8208	30.2987	1.8083	0.687	717.7	5.101	0.071	0.758
10A	30.0494	31.0183	31.0123	0.9629	31.0099	0.9605	0.249	3786.2	12.35	0.378	0.627
10C	28.3959	29.9651	29.9609	1.5650	29.9599	1.5640	0.064	2385.6	36.86	0.238	0.302
10F	27.8184	28.8592	28.8530	1.0346	28.8513	1.0329	0.164	5642.9	25.73	0.563	0.728
11B	29.6211	30.3994	30.3973	0.7762	30.3942	0.7731	0.399	2525.6	29.91	0.252	0.651
11C	29.1558	30.6298	30.6199	1.4641	30.6171	1.4613	0.191	6705.5	9.571	0.669	0.861
								Minimum			0.127
								Maximum			2.056
								Mean			0.757
								Median			0.681
								Standard Deviation			0.360

Appendix A9 Well database for peizometer nests

Explanation

a* Well number	X Coord. (m)	Y Coord. (m)	*b Well order	c* Land surface elevation (m)	d* Screen center elevation (m)	WATER LEVEL MEASUREMENTS August 3-4, 1989 (m)	September 30, 1989 (m)	October 29-November 1, 1989 (m)	June 21-July 5, 1990 (m)	August 8, 1990 (m)	November 26, 1990 (m)	June 11-27, 1991 (m)
LAKE-WOODSY AREA												
925 a	**75.55**	**183.18**	**2**	**432.36**	**423.50**	**422.69**	**422.64**	**422.62**	**422.63**	**422.50**	**422.48**	**422.48**
925 b	**75.20**	**184.60**	**4**	**432.32**	**405.15**	**422.87**	**422.83**	**422.81**	**422.82**	**422.69**	**422.68**	**422.68**
925 c	**76.72**	**184.24**	**3**	**432.33**	**423.01**	**422.73**	**422.67**	**422.65**	**422.66**	**422.53**	**422.51**	**422.51**

a* Wells which are bold typed are wells used during this study for determination of vertical hydraulic pressure gradients. Well plain typed were not used due to unreliability of well configuration data, lack of water level records, or location. An asterisk with a well means the well is part of the well series immediately below it.

b* Well order indicates the order in which wells screen depths increase. A "1" would indicate a water table well. In the example above, well 925a is next after the water table well, well 925b is the deepest well screen, and the screen for well 925c is between those of wells 925a and 925b.

c* All elevations are in meters above mean sea level.

d* The elevation at which the head level is measured from is set as halfway between the screen top and bottom. Screen centers were calculated from well configuration data.

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Well number	X Coord (m)	Y Coord. (m)	Well order	Land surface Elevation (m)	Screen center Elevation (m)	August 3-4, 1989 (m)	September 30, 1989 (m)	October 29-November 1, 1989 (m)	June 21-July 5, 1990 (m)	August 8, 1990 (m)	November 26, 1990 (m)	June 11-27, 1991 (m)
LAKE-WOODSY AREA												
925 a	75.55	183.18	2	432.36	423.50	422.69	422.64	422.62	422.63	422.50	422.48	
925 b	75.20	184.60	4	432.32	405.15	422.87	422.83	422.81	422.82	422.69	422.68	
925 c	76.72	184.24	3	432.33	423.01	422.73	422.67	422.65	422.66	422.53	422.51	
955 a	54.30	169.766	1	433.31	422.33	422.80	422.74	422.73	422.73	422.66	422.57	
955 b	54.53	170.263	2	433.33	422.62	422.82	422.74	422.73	422.68	422.66	422.57	
954 a	43.75	123.089	2	433.23	422.08	423.00	422.95	422.94	422.93	422.88	422.79	423.01
954 b	43.76	122.395	1	433.45	422.35	423.01	422.97	422.95	422.94	422.89	422.81	425.00
515 a	26.39	74.84	1	432.98	423.07	423.22	423.17	423.16	423.14	423.11	423.02	423.12
515 b	25.85	73.78	2	432.95	420.40	423.23	423.18	423.17	423.15	423.11	423.01	423.16
807 a	32.76	73.84	1	432.99	422.57			423.19	423.15	423.10		423.01
807 b			2	433.01	422.71			423.17	423.17			
801 a	24.44	62.92	1	432.98	422.73	423.24	423.20	423.18	423.17	423.13	423.04	423.14
801 b	23.40	64.48	2	432.90	417.99	423.25	423.20	423.19	423.17	423.14	423.05	423.52
KETTLE AREA												
308* a	-58.80	38.21	2	426.96		423.37	423.32	423.31	423.29	423.23		423.27
702 a	-60.34	40.07	1	427.11	423.73	423.47	423.43	423.41	423.40	423.36		423.36
702 b	-57.87	41.09	4	426.93	410.98	423.52	423.47	423.46	423.44	423.40		423.43
702 c	-60.77	40.72	3	427.15	420.09				423.47	423.40		423.41
706 a	-37.72	-3.91	1	432.18	423.50	423.46		423.40	423.38	423.36		423.34
706 b	-36.90	-4.36	2	432.21				423.40	423.39	423.36		423.37
SPRAY ZONE AREA												
523* a	-53.58	-115.69	2	430.19	423.62	423.91		423.67	423.64	423.61	423.51	423.62
707 a	-54.13	-117.62	1	430.18	423.11	423.73	423.68	423.67	423.64	423.60	423.51	423.62
707 b	-52.99	-119.71	3	430.25	421.18	423.25	423.69	423.68	423.64	423.62	423.52	423.62
707 c	-52.00	-117.38	4	430.31	419.35	423.73	423.71	423.66	423.64	423.60	423.51	423.61
707 d	-51.81	-115.56	5	430.33	416.33	423.73	423.73	423.65		423.59	423.51	423.61
957 a	-13.20	-219.359	1	427.81				423.75	423.76	423.77		424.01
957 b	-13.16	-218.34	2	427.89				423.91	423.91	423.77		423.79
310 a	-96.61	-238.76	2	433.01	422.95	423.97	423.92	423.90	423.87		423.81	
310 b	-97.49	-239.12	5	433.03	406.29	424.00	423.95	423.93	423.81		425.25	
310 c	-97.11	-238.13	4	433.03	415.95	423.89	423.85	423.83	423.82		424.01	
310 d	-97.89	-239.60	1	433.11	423.55	424.00	423.95	423.93	423.73		423.42	
310 e	-100.36	-241.28	3	432.89	422.83	424.00	423.96	423.93	423.90	423.87	423.78	
CENTRAL AREA												
530 a	10.56	32.61	1	432.61	422.49	423.03	422.97	422.97	422.94	422.91	422.82	422.91
530 b	10.56	32.02	2	432.90	422.13	423.33	423.29	423.30	423.24	423.22	423.12	423.25
530 c	10.00	31.24	3	432.92	420.17	423.33	423.29	423.28	423.25	423.22	423.12	423.21
318 a	1.13	0.38	1	432.58	423.91	423.44	423.38	423.38	423.35	423.35	423.22	423.53
318 b	1.41	1.01	2	432.67	423.51	423.56	423.51	423.50	423.48	423.43	423.35	423.46
417 a	63.48	23.49	5	431.60	415.79	423.29	423.25	423.24	423.22	423.17		423.25
417 b	62.24	22.42	3	431.58	418.90	423.29	423.26	423.24	423.22	423.19		423.20
417 c	61.04	21.42	1	431.67	424.02	423.29	423.36	423.24	423.23	423.16		
417 d	63.77	21.92	2	431.50	422.32	423.29	423.35	423.24	423.19	423.19		423.24
417 e	58.60	24.00	4	431.86		423.22	423.22	423.22	423.18	423.16		423.00
418 a	39.79	5.27	4	432.20	415.47	423.36	423.33	423.31	423.29	423.26		423.26
418 b	38.82	4.59	3	432.18	419.09	423.37	423.33	423.32	423.29	423.27		423.28
418 c	39.90	3.93	2	432.15	422.83	423.47	423.33	423.31	423.01	423.27		423.27
418 d	37.72	3.74	1	432.20	423.83	423.37	423.34	423.32	423.60	423.27		423.27
533 a	-7.96	-20.53	1	432.45	423.45			423.47	423.40	423.39	423.28	423.45
533 b	-7.97	-21.32	3	432.47	421.76	423.50	423.45	423.47	423.41	423.39	423.29	
533 c	-7.98	-21.91	4	432.45	420.50	423.50	423.45	423.43	423.10		423.28	
533 d	-7.28	-18.72	2	432.56	423.69			423.41	423.40	423.37	423.27	
420 b	-3.57	-27.07	1	432.23	419.43				423.42	423.37	423.29	
420 c	-2.43	-26.07	2	432.24	416.13				423.41	423.37	423.29	
532 a	-3.64	-10.97	1	432.37	423.40	423.47	423.42	423.41	423.38	423.35	423.26	
532 b	-3.66	-11.64	3	432.35	419.49	423.47	423.42	423.46	423.38	423.36	423.27	422.96
532 c	-3.68	-12.30	2	432.37	420.63	423.47	423.42	423.42	423.38	423.35	423.26	423.37
532 d	-3.63	-9.10	4	432.38	417.36	423.45	423.40	423.39	423.37	423.34	423.25	423.55
REGIONAL AREA BEHIND WETLAND												
401 a	49.33	-485.01	1	429.83	423.67			424.23	424.19	424.16		424.17
503 a	49.66	-482.95	3	429.86	405.48			424.25	424.21	424.17		424.21
504 a	51.53	-484.50	2	429.84	419.37			424.25	424.22			424.22

Appendix A10 List of Notations & Conversion Factors

a	area of core sample
acre	(1 acre = 4047 m^2 = 0.4047 hectares)
A	area of marriotte bottle
°C	degree Centigrade
C	constant=100, ($cm^{-1}s^{-1}$)
cm	centimeter (2.54 cm = 1 inch)
d	day
d_{10}	effective grain diameter, cm
E_p	elevation of water level at peak stage, m above mean sea level
E_r	elevation of water on recession stage at same time as peak stage, m
Et	evapotranspiration , in/yr or m/d
Et surface	elevation where maximum *Etp* occurs if the water table is at or above this surface, m
Etp	potential evapotranspiration rate, in/yr or m/d
ft	feet (1 ft = 0.3048 m)
gpm	gallons per minute
hectare	area, (1 hectare = 10^4 m^2)
m/mile	gradient
gm	gram
h	hydraulic head, l*
H	head loss, l
H_i	height of initial reading above tailwater
H_f	height of final reading above tailwater
K	hydraulic conductivity, l/t
K_i	homogeneous hydraulic conductivity of individual layer, l/t
Km	kilometer (Km = 0.621 miles)
K_x	equivalent horizontal hydraulic conductivity, l/t
K_{xx}	Hydraulic conductivity in the X-direction, l/t
K_{yy}	Hydraulic conductivity in the Y-direction, l/t
K_z	equivalent vertical hydraulic conductivity, l/t
K_{zz}	Hydraulic conductivity in the Z-direction, l/t
l	liter
L	length of sample
m	meter (1 m = 3.28 ft)
mm	millimeter
mo	month
msl	mean sea level
mya	million years ago
N/m^2	newton per square meter, SI unit for psi
ppm	parts per million
psi	pounds per square inch
Q	volume of flow
R	recharge, in
Rf	final water level in marriotte bottle
Ri	initial water level in marriotte bottle
s	second
Ss	specific storage, (m^{-1})
Sy	specific yield, unitless
t	time
µ	Darcian velocity, l/t
V	length of column of water passing through sediment (Rf - Ri), l
W	volumetric flux per volume (s^{-1})
W_c	weight of crucible, gm
W_{ds}	weight of crucible and oven dried soil before ignition, gm
W_{is}	weight of crucible and oven dried soil after ignition, gm
W_{ps}	weight of crucible and soil after phosphoric acid treatment, gm
yr	year
z_i	layer thickness
*	l = length, l/t = length per time

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